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The Felton-Herron Creek Mill Creek Pilot Watershed Study

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The effects of fruit orchard farming and land application of wastewater on transport of pollutants to the Great Lakes were studied in two sub-studies. In the Mill Creek Study, movement of pesticides from fruit orchards was the primary concern. Only eight pesticides were transported in appreciable quantity. The major forms exported were the residual, presently unused, chlorinated hydrocarbons. Most pesticides were transported on suspended solids. Pesticides lost in order of amount lost were DDT, DDE, Atrazine, Dieldrin, DDD, Simazine, Aldrin, and Guthion. Most pesticides lost were associated with past farming practices or corn cultivation. Guthion was the only major pesticide lost associated with present fruit orchard farming practices. The Felton-Herron Creek Study demonstrated that improper management of land application systems for recycling municipal wastewater can lead to appreciable loading of streams with major nutrients, especially nitrogen. Proper management can control these losses. Perennial crops and oldfield systems are efficient at uptake of both N and P throughout the growing season and offer excellent wastewater renovation potential. Annual crops such as corn are not efficient at nitrogen uptake during the first five to seven weeks, but are efficient after that. Losses of N to ground water or runoff often approach input amounts in wastewater irrigated forests. A variety of harvest managements and winter spray feasibility were investigated in this study and are discussed in detail.

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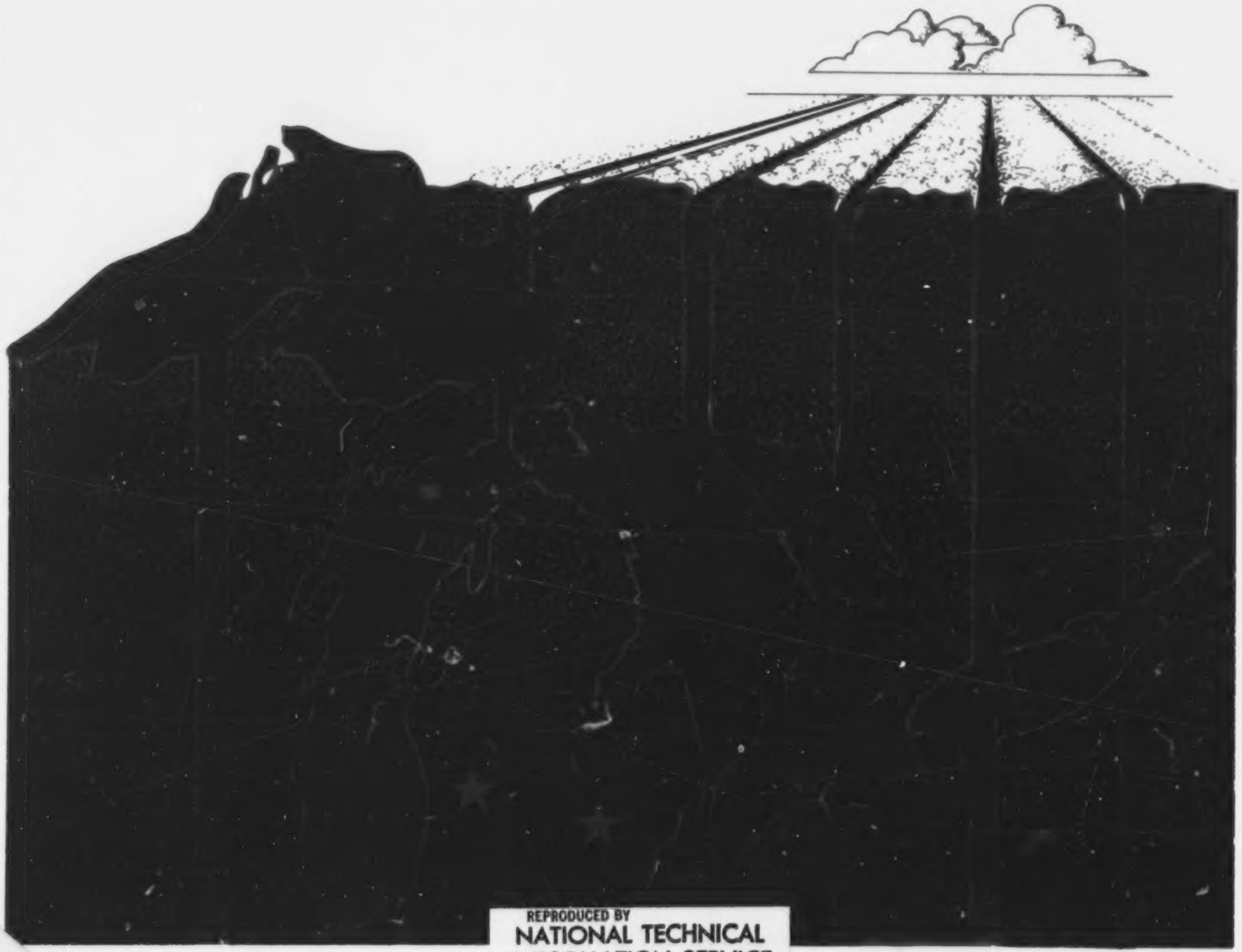

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The Great Lakes National Program Office (GLNPO) of the U.S. EPA, was established in Region V, Chicago to provide a specific focus on the water quality concerns of the Great Lakes. GLNPO provides funding and personnel support to the International Joint Commission activities under the US-Canada Great Lakes Water Quality Agreement.

Several land use water quality studies have been funded to support the Pollution from Land Use Activities Reference Group (PLUARG) under the Agreement to address specific objectives related to land use pollution to the Great Lakes. This report describes some of the work supported by this Office to carry out PLUARG study objectives.

We hope that the information and data contained herein will help planners and managers of pollution control agencies make better decisions for carrying forward their pollution control responsibilities.

Dr. Edith J. Tebo
Director
Great Lakes National Program Office

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THE FELTON-HERRON CREEK, MILL CREEK PILOT WATERSHED STUDIES

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The findings and views expressed in this report are those of the project investigators and do not necessarily reflect the views of the International Joint Commission or the International Reference Group on Great Lakes Pollution from Land Use Activities.

ABSTRACT

Two land uses, (1) fruit orchard farming and (2) land application of municipal wastewater irrigation were studied to assess the sources, forms, and amount of pollutants that are transported from these areas to the boundary waters of the Great Lakes. The primary concern of the Mill Creek study was the movement of pesticides from fruit orchards while the primary concern of the wastewater irrigation study (Felton-Herron Creek study) was the transport of nutrients.

Analyses were conducted for 57 different pesticides on both suspended sediment and dissolved in water in the Mill Creek study. Of the eight pesticides found in appreciable quantities, the major forms exported were the chlorinated hydrocarbons, although they have not been used for several years. Most of the pesticides were transported on suspended solids. The pesticides lost in order of amount lost were DDT, DDE, Atrazine, Dieldrin, DDD, Simazine, Aldrin, and Guthion. Most pesticides lost were associated with past farming practices (e.g., DDT, DDE, DDD) or corn cultivation in the watershed (e.g., Atrazine) with Guthion being the only major pesticide associated with fruit orchard farming lost from the watershed. It was lost in only very small amounts. Losses of suspended sediment from this watershed were low compared to most midwestern watersheds while nutrient losses were comparable to losses from other agricultural watersheds in the Great Lakes Basin.

The Felton-Herron Creek study demonstrated that improper management of land application systems for recycling municipal wastewater can lead to appreciable loading of streams with all the major nutrients, especially nitrogen. Proper management of such systems will control these losses. Perennial crops and oldfield systems are very efficient at uptake of both N and P throughout the growing season and offer excellent wastewater renovation potential. Annual crops such as corn are not efficient at nitrogen uptake during the early growth phase (first five to seven weeks). After that, they are also very efficient at nitrogen uptake. Late successional forests are not efficient at nitrogen uptake and losses to groundwater or runoff often approach input amounts. A variety of harvest managements and winter spray feasibility were also investigated in this study. The effect of these managements on nutrient losses are also discussed in detail.

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SECTION 1

INTRODUCTION

The Felton-Herron/Mill Creek Study was initiated in 1974 as one of the Task C Pilot Watershed Studies of the studies requested by the Great Lakes Pollution from Land Use Activities Reference Group (PLUARG) appointed by the U.S.-Canada International Joint Commission for Great Lakes Research.

Two Michigan subwatersheds were included as representative U.S. watersheds for land drainage studies on the input of polluting materials to the Great Lakes. One, Felton-Herron Creek, is a subwatershed of the Grand River with features well suited for investigating land drainage from a municipal wastewater, land treatment area. The other, Mill Creek, is also a tributary of the Grand River and represents a basin typical of the large fruit growing area of southwestern lower Michigan.

STUDY OBJECTIVES

The general purpose of the pilot watershed studies conducted in the State of Michigan was to evaluate land drainage from agricultural or other land uses not adequately represented in the other U.S. Watershed Studies. The two selected for inclusion significantly extend the resolution of the impact of unique land uses to streams tributary to the Great Lakes.

Felton-Herron Creek

Recent laws have mandated consideration of land application systems as an alternative to more conventional waste treatment facilities. Such systems have proliferated in recent years so that several thousand hectares in the U.S. are presently being irrigated with municipal and industrial effluent. Such systems often discharge to streams via tiles, surface runoff, or subsurface seepage and represent potentially significant non-point pollution sources both as a consequence of high concentration of nutrients in the irrigated water and as a result of excessive leaching of native, residual nutrients from organic matter in the soil or from built-up fertilizer residues. Thus, quantification of runoff and subsurface seepage from such sites is needed as a first step in development of management techniques to control such surface and groundwater contamination. Furthermore, land application systems when replacing conventional wastewater treatment systems represent a shunt from a point source to a non-point source of potential pollutants. This concept must be considered when pollutant loading extrapolations are estimated for future years.

Mill Creek

The objective of this research effort was to assess the magnitude of the pesticides and sediment transported from a watershed typical of the kind of agriculture subject to the most intensive pesticide usage in the Great Lakes Basin; fruit orchard farming.

The pesticide transport process can be divided into two categories: (1) pesticide transported in solution, and (2) pesticide adsorbed to particulate matter and convected along with the sediment load of the stream. This distinction is necessary if one is to accurately identify the source of the problem.

The removal and subsequent transport of agricultural non-point source pollutants are directly related to the rainfall-runoff. Overland flow is responsible for the initial movement of pollutants from the land surface to the stream. Once in the stream, the pollutant may be transported considerable distances by the stream flow. In the particular case of pesticides the quantity transported is related to the solubility and adsorptive characteristics of the pesticide considered. The translocation of pesticides that are adsorbed to or coated on sediment particles depends on the many variables influencing the capability of a stream to transport sediment, whereas those that are water soluble will be convected in amounts that are directly proportional to their concentration level and the stream discharge.

In view of the above description of the processes responsible for the transport of pesticides, the major ojective of our research effort was to determine the relative amount of pesticide transported on the suspended solids and in solution. As a result of such a determination it was then possible to ascertain the magnitude and source of this non-point source problem.

SECTION 2

CONCLUSIONS

FELTON-HERRON CREEK

Application of wastewaters to land offers a waste treatment alternative to the conventional "concrete and steel" wastewater treatment plant, especially for small to medium sized communities. This technology has already been adopted by several communities in the Great Lakes Basin, and its use is expanding rapidly. These land treatment facilities offer the potential of producing an end product which is of the same or higher quality than output from a conventional tertiary sewage treatment facility, while at the same time offering the advantage of recycling nutrients in the wastewater into usable food and fiber. This advanced treatment is often achieved at much lower costs than the more conventional advanced technology.

Since land treatment technology is relatively new in the Great Lakes Basin, many questions about management alternatives for such systems exist as well as questions about safety from both a health and an environmental standpoint. For example, land application diffuses a point source so that it becomes a non-point pollution source. It also increases the recharge of groundwater with this reclaimed wastewater. Thus, this technology must be subjected to a thorough evaluation in a critical and searching manner before it is even more widely adopted. At the same time, management alternatives for operation of such systems, if they prove feasible, must be developed so that the designer and operator of such systems can evaluate the various trade-offs associated with each management alternative.

Conclusions stemming from the Felton-Herron Creek Studies in this regard can be summarized as follows:

> Overall the oldfield and cropland sites resulted in discharges of nutrients greater than non-irrigated sites. Proper selection of vegetation, of irrigation rate and of harvest management would minimize

discharges of N and P. Removal of vegetative material would minimize reliance of the sites capacity to retain the nutrients against the recharge flow.

Several general conclusions can be made. These include:

(1) The type of crop selected is very important in management of land irrigation systems for the prevention of NO_3-N losses.

  a.) Annuals such as corn do not take up much N during the early part of the growing season. Thus, such crops should be irrigated at rates that will just replace evapotranspirational losses (about 2.5 cm/week in Michigan) for the early growth period with increased irrigation up to 7.5 cm/week after about the first five to seven weeks of growth.

  b.) Perennial grasses are the most effective cropped vegetation at removing N from wastewater. Harvesting can extend active uptake through October. Thus, effective N removal by vegetative uptake can be expected from April through October with proper managements with rates up to 10 cm/week of wastewater application.

  c.) Legumes such as alfalfa are about as effective as perennial grasses at N removal except that irrigation should be limited to 2.5 cm/week for a three week period after harvest since uptake is reduced during this period.

  d.) Oldfield vegetation is very effective at removing N from wastewater. Harvesting can extend active uptake through October. Oldfield vegetation is as effective as perennial grasses at removing N from wastewater. Mowing without harvesting for grasses and probably for oldfield vegetation is just as effective at extending the active uptake of N through October at least through the first few years of spray irrigation. If the system were not harvested, ultimate breakthrough of both N and P would be expected. If one wanted to build up the organic content of the soil, mowing could be used for the first several years, followed by harvesting after that.

(2) Soils are effective at P sorption so that P concentrations of water leaching past the root zone on irrigated sites approaches background levels. Thus, groundwater loading with P is a function of leachate quantity but concentrations are low enough that there are no problems with groundwater contamination.

(3) Runoff from spray sites should be avoided. Tiles draining such sites often have direct surface connections through sand lenses which lead to discharge of water with P concentrations over one mg/ℓ during some actual spray events. These peak concentrations are of short duration and drop rapidly as actual irrigation ceases. On a mass balance basis, such high concentrations account for only a small percentage of discharged water and P removal by tiled systems is high (over 80%).

(4) Late successional beech-sugar maple forests are not efficient at removal of N from wastewater. Such mature forests should not be used for wastewater renovation since nitrate-nitrogen leaches to groundwater at about input concentrations.

(5) Winter wastewater spray irrigation in the Great Lakes Basin is feasible. The accumulated ice layer insulates the soil, prevents it from freezing, and allows infiltration of water during winter months. Since vegetative uptake mechanisms are not active, applied inorganic nitrogen will ultimately leach through to groundwater or runoff. Thus, winter spray irrigation of wastewater should only be done with wastewater that is low in inorganic nitrogen (e.g., from storage lagoons where summer plant activity has stripped nitrogen by raising the pH above the pK of ammonia gas). The early spring ice melt period is characterized by high levels of phosphorus in runoff since the saturated soil does not allow infiltration. This runoff could be controlled by diking to retain the water on-site until it infiltrated.

MILL CREEK

It would appear that the predominant factor affecting the appearance of pesticide problems in the Great Lakes is the nature of the chemical formulation of the pesticide itself. Persistent compounds such as the chlorinated hydrocarbons are still being transported to the lakes despite their lack of use for several years in the watershed. Transport of these compounds is tied closely with the movement of suspended sediments, thus measures to control sediment movement would also control the movement of chlorinated hydrocarbons. The problem in the lakes however, is apparently slowly improving as these compounds reach their ultimate sink in some unavailable compartment of the ecosystem or as they are degraded into more harmless forms. In short, this problem should take care of itself in time assuming no further use of these compounds.

Pesticide losses from Mill Creek in order of amount lost were DDT, DDE, Atrazine, Dieldrin, DDD, Simazine, and Guthion. The sediment and water were analyzed for 49 other pesticides; no appreciable amounts were detected. Most pesticides such as the chlorinated hydrocarbons that were lost, were associated with past farming practices. Of the pesticides currently in widespread use in the Mill Creek watershed, Atrazine and Guthion do appear in Mill Creek. Their significance as a problem in the Great Lakes is unclear at this time.

SECTION 3

RECOMMENDATIONS: IMPLICATIONS FOR REMEDIAL MEASURES

FELTON-HERRON CREEK

The application of secondary municipal effluent on land offers a viable, economically attractive alternative to conventional, tertiary treatment technology, especially for small to medium sized cities where land is available. Such land application will work for a variety of cropped and non-cropped ecosystems providing proper management techniques are used. These proper management techniques involve selection of a site with infiltration rates of 5 cm/week or better and preferably with soils with sufficient clay and organic content to serve as sorption sites for P, heavy metals, etc. Assuming the proper site is selected, proper management techniques include: (1) selection of the vegetation type to give maximal wastewater cleanup at the lowest possible cost, and (2) selection of the harvest regime to maximize nutrient uptake and removal. In this regard, the following vegetative types offer most potential:

(1) Perennial grasses and oldfield vegetation offer the best phosphorus and nitrogen removal potential; however, they offer least economic return. Such systems can renovate from 7.5 to 10 cm/week of secondary effluent.

(2) Alfalfa offers excellent renovation potential, but wastewater application should be limited to evapotranspirational losses for the first three weeks following each harvest since the system is subject to nitrogen breakthrough during that period. At other times, the irrigation rate can be as high as 7.5 cm/week with no problem.

(3) Annuals such as corn are excellent at removing N and P from as much as 7.5 cm/week of wastewater after the

first five to seven weeks of growth. Annuals are subject to losses of N and P in leachate during the attainment of significant root biomass (five to seven weeks for corn), and irrigation should be limited to evapotranspirational losses during that period. Annuals also cease active uptake earlier in the fall than do perennial grasses and oldfield vegetation.

(4) Older forests remove very little N from wastewater and leachate from such sites often exceeds drinking water standards for nitrate. Older forests should not be used for application of "typical" secondary effluent. They do offer excellent phosphorus removal and infiltration capacity for wastewater low in inorganic N. Such low inorganic nitrogen wastewater is available from the third or fourth cell of most lagoon systems due to N stripping processes brought about by plants in the lagoons. Plantations of young, fast growing trees with grasses between tree rows are effective at renovation of "typical" secondary effluent.

Selection of the proper harvest regime is also important in limiting nutrient losses from land application systems. Experiments on this project demonstrated the following:

(1) Harvesting grasses or oldfield vegetation extends the active growth and nutrient uptake period through October. Thus, these systems are effective at N and P removal from April through October in Michigan.

(2) Mowing was as effective as harvesting in maintaining growth of grasses through October. It was also as effective as harvest in preventing nutrient losses; however, eventual breakthrough would likely occur if vegetation was not harvested for several years.

(3) Two harvests of oldfield vegetation per year (June and September) removed the most nutrients. This

nutrient removal accounted for essentially all of the N added in wastewater and most of the P. One harvest in June only resulted in extension of the growth period through October but less N was removed in biomass than was applied.

Some other findings which have important implications for management of wastewater land application systems are:

(1) Tile drain systems result in peak discharges of P that are greater than one mg/ℓ. These peak losses occur as a result of sand lenses or direct connections to the tiles. Such losses are short-lived and represent only a small fraction of P applied in wastewater. Nevertheless, avoidance of tile systems would result in lower P losses in runoff.

(2) Water-logging an older forested site apparently promoted rapid denitrification and resulted in groundwater leachate low in inorganic N. However, runoff losses of inorganic N and P were very high in this study. If such sites could be water-logged without significant runoff losses, excellent nitrogen removal could be obtained. The intensive management needed for such a system means that this technique probably should not be widely adopted.

(3) Winter irrigation in Michigan is feasible. Insulation by the accumulated ice-pack keeps the ground from freezing and results in excellent winter infiltration. However, nitrate-nitrogen losses to groundwater will exceed the drinking water standard if "typical" secondary effluent is applied. Such winter application could be used for irrigation from storage lagoons which have low N water as a result of in-lagoon processes. This application of water from lagoons would lower the winter storage requirements for land application systems. The first spring runoff from such

winter spray systems is high in P because of freeze out processes and saturated ground causing overland flow. Thus, diking to retain such water on the site would be needed.

In conclusion, land application systems for recycling secondary municipal effluent offer an excellent alternative to conventional tertiary treatment for small to medium sized communities. Such systems will require rather precise management and, thus, will require trained personnel to operate efficiently. Efficiently operated systems are better than conventional tertiary systems since little, if any, discharge to surface water need occur. Thus, these systems meet the zero discharge requirements for surface waters and, at the same time, offer a means of replenishing the dwindling groundwater supplies with good quality water.

MILL CREEK

The major pesticide losses from the Mill Creek watershed are still the chlorinated hydrocarbons which have not been used for several years. Most of these pesticides are lost as a result of soil erosion and transport of existing stream sediments. Thus, remedial actions would have to include efforts to reduce soil erosion. The problem in the Great Lakes, however, is apparently slowly improving as these compounds reach their ultimate sink in some unavailable compartment of the ecosystem or as they are degraded into more harmless forms. In short, this problem should take care of itself in time assuming no further use of these compounds.

Of the currently used pesticides, Atrazine and Guthion do appear in Mill Creek. Both are transported predominantly on sediments. Thus, remedial actions that limited soil erosion would reduce loading of these compounds. Atrazine is fairly persistent in soils (300-500 days) and represents the greatest contribution of any currently used pesticide from the Mill Creek watershed. The significance of either Atrazine or Guthion in terms of an environmental problem to the Great Lakes is unknown. Misuse and accidents with pesticides can be expected no matter how strict a particular set of regulations is enforced. The only safeguard under these circumstances is to ban the manufacture and use of formulations that could cause long term problems in the event of a single accidental introduction.

Suspended sediment losses from the Mill Creek watershed are already low compared to other midwestern watersheds. Nutrient losses are comparable to losses from other agricultural watersheds in the Great Lakes Basin.

In conclusion, losses of pesticides, nutrients, and sediments from the Mill Creek watershed are not excessive compared to other watersheds in the Great Lakes Basin. Thus, no immediate remedial actions are recommended. Long term remedial actions that should be pursued include adoption of best management practices aimed at further reducing sediment losses and adoption of integrated pest control programs which further reduce pesticide use in the watershed.

SECTION 4

INTRODUCTION TO FELTON-HERRON CREEK WATERSHED STUDIES

Recent laws have mandated consideration of land application systems as an alternative to more conventional waste treatment facilities. Land irrigation for treatment of municipal wastewaters occurs on only a small percentage of land area in the Great Lakes Region. In Michigan, for example, 40 small communities ranging in size from 100 to 6,600 persons are presently utilizing some form of land irrigation. These 40 small communities serve a combined population of over 59,000 people. In addition, the Muskegon system serves a total population of over 79,000 people. Thus, land treatment of municipal effluent is already used for nearly 140,000 people in Michigan alone, and this technology is expanding as other small communities adopt it. While land treatment of wastewaters has been shown to effectively lower nutrient concentrations to levels comparable to or lower than those achieved by conventional waste treatment facilities, the impact of diffusing these point sources to non-point sources and the impact of various vegetation management schemes on these non-point discharges through field tiles, seepages, runoff, or groundwater recharge has not been well documented. In studies at Michigan State University, the impacts of various irrigation and vegetative management schemes on discharge of phosphorus and nitrogen to streams and groundwater in the Great Lakes Region have been investigated. These studies form the core of the Felton-Herron Creek "Watershed" study.

The general objectives of the Felton-Herron Creek portion of the study were to (1) develop management and design criteria to minimize surface and subsurface water contamination in wastewater irrigation systems, and (2) arrive at reasonable pollutant loading values associated with these practices.

DESCRIPTION OF STUDY AREA

The Felton-Herron Creek study was located on the Water Quality Management Facility (WQMF) on the Michigan State University campus near East Lansing, Michigan. The project location is in the Red Cedar River watershed, a tributary to the Grand River which enters Lake Michigan at Grand Haven, Michigan. The exact location of the WQMF is 42°43' 50" north latitude and 84°28' 58" longitude or T4N, R1, 2W, secs. 1, 6, 31, 36, Ingham County, Michigan.

Basically, the Water Quality Management Facility consists of two elements: (1) a series of four man-made lakes with a total surface area of 16 ha and a mean depth of 1.8 m which receives secondary effluent, and (2) a 58 ha tract of land used for spray irrigation of wastewater (Figure 4-1). The total area of the spray site is 127 ha when aerosol buffer zones are included.

The Water Quality Management Facility received secondary effluent via pipeline (Figure 4-1, A) from the City of East Lansing's conventional extended aeration, activated sludge wastewater treatment facility at a rate of 1975 m^3/day during 1977 (January 1 to October 28). About 39% of this 594,335 m^3 of water was spray irrigated, another 39% was discharged via Felton Drain and the remainder was lost by evaporation or deep seepage (TABLE 4-1). The total amount irrigated on the various ecosystem types (Figure 4-2) is listed in TABLE 4-2. All irrigated wastewater was a mixture of secondary effluent directly from the pipeline from the East Lansing Sewage Treatment Plant and water that back-siphoned into the pipe from Lake 1 (Figure 4-1) as a result of the rapid withdrawal rate from the pipe during irrigation. All water was chlorinated prior to spray irrigation. Application rates on all land study areas in 1976 was similar to 1977. However, an additional 1215 m^3/day of wastewater were received in 1976 with corresponding greater lake throughput and discharge to Herron Creek (Figure 4-1, C) until August 26 or to Felton Drain (Figure 4-1, D) thereafter.

Studies partially or completely funded as part of the Pilot Watershed Studies of IJC include crop and grass management plot studies (Figure 4-2, A), baseline watershed studies (Figure 4-2, B), forest studies (Figure 4-2, D, E, and an area east of E), oldfield studies (Figure 4-2, G, H, I) and

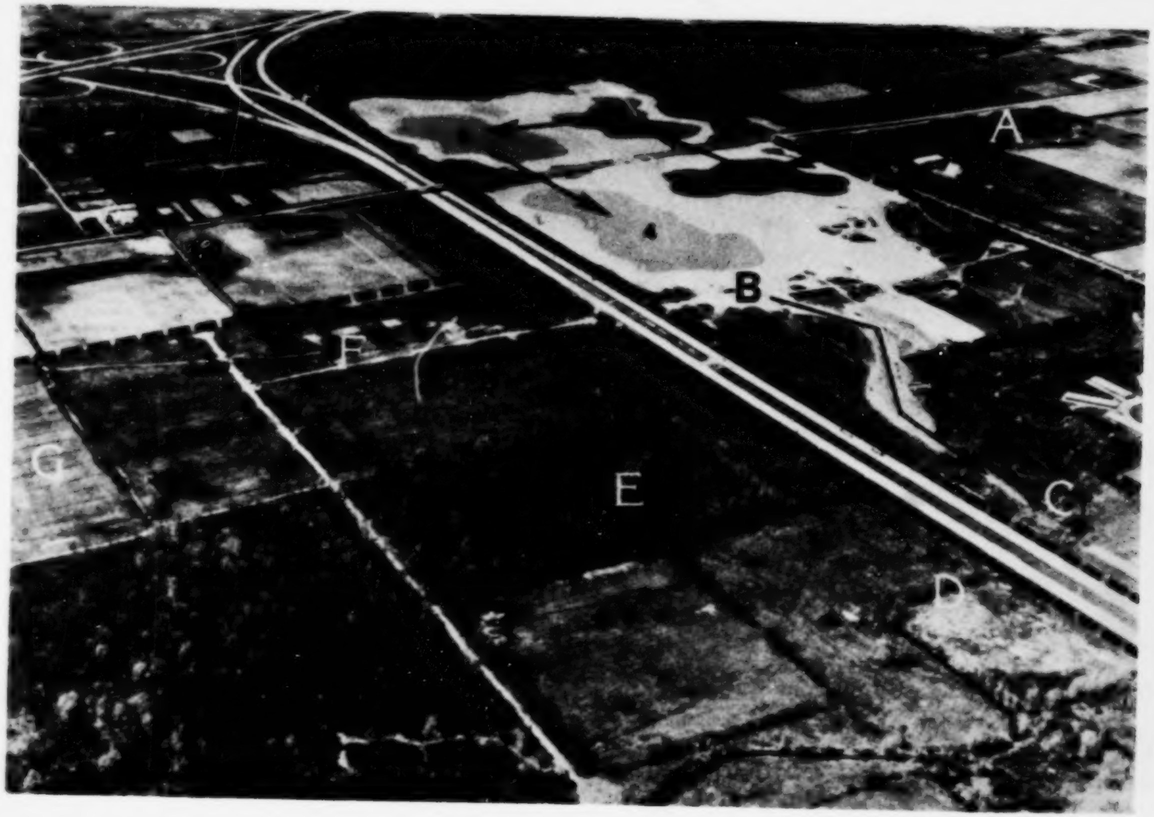

Figure 4-1. Looking northwest at Lakes 1, 2, 3, and 4. 'A' is the influent pipeline, 'B' is the outlet from Lake 4, 'C' is the Herron Creek drain, 'D' is Felton Drain, 'E' is mature woods, 'F' is field crops, and 'G' is a tree plantation.

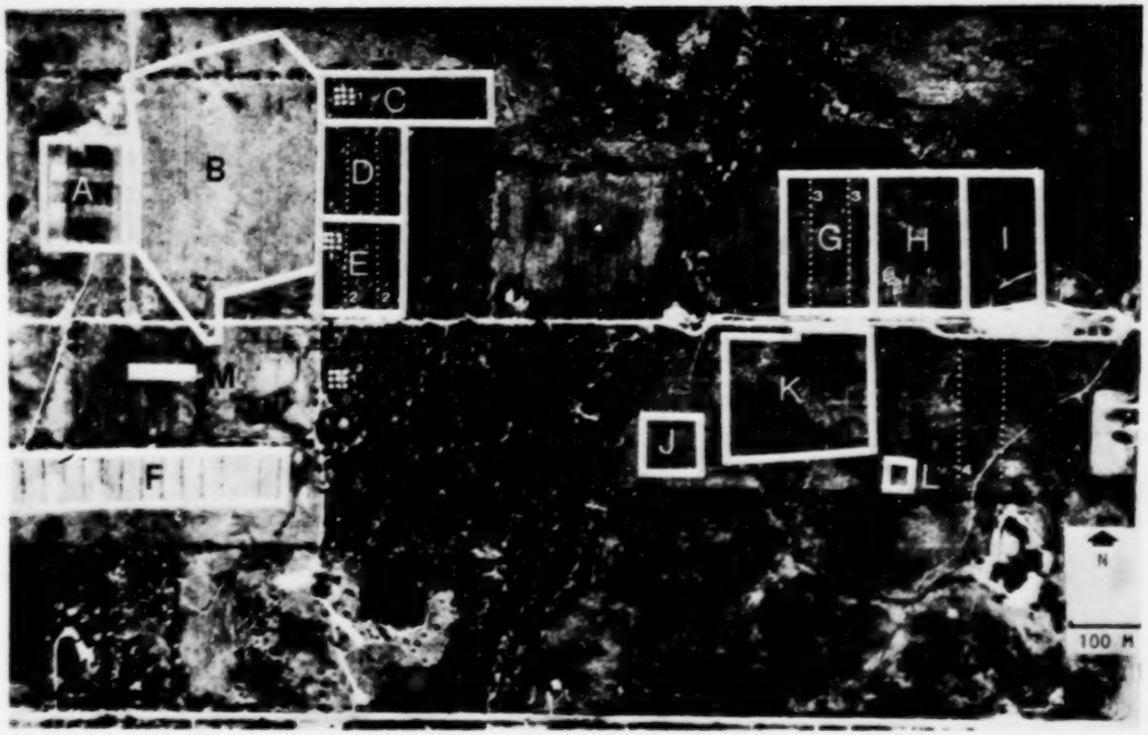

Figure 4-2. Photograph of the Spray Irrigation Area showing major research areas. Area 'A' is the crop and grass management plot; 'B' is the baseline watershed; 'D', 'E' and the area east of 'E' is the forest study area; 'G', 'H' and 'I' constitute the site of the old-field studies; 'K' is the winter irrigation area; and 'F' is a tree plantation.

TABLE 4-1: SUMMARY OF WATER FLOWS FOR THE WATER QUALITY MANAGEMENT FACILITY, JANUARY 1 TO OCTOBER 28, 1977

	Amount (cubic meters)	Percent of Total Input
Wastewater Input	594,335	100.0
Discharge to Felton Drain from Lakes	233,093	39.2
Lake Evaporative and Seepage Losses	130,621	22.0
Spray Irrigation	230,621	38.8

TABLE 4-2: SUMMARY OF WASTEWATER IRRIGATION ON THE LAND SITE FOR 1977 (JANUARY 1 TO OCTOBER 28)

Study Area	Amount (cubic meters)	Percent of Total Input
Crop Plots	19,700	8.5
5 cm/week Mature Forest Plot	19,555	8.5
10 cm/week Mature Forest Plot	39,110	17.0
5 cm/week Oldfield Plots	23,404	10.2
10 cm/week Oldfield Plots	45,172	19.6
5 cm/week Oldfield Winter Spray Area	39,621	17.2
Tree Plantation	34,518	15.0
Other	9,541	4.1
TOTAL	230,621	100.0

winter spray studies (Figure 4-2, K). Also, studies of water quality and nutrient loadings at stations upstream and downstream of the entire land spray site were conducted in Felton Drain (Figure 4-1, D). Methods, results, discussion, and conclusions from each of the studies will be presented in Sections 5 to 9.

The soils on the spray irrigation site are highly variable both vertically and horizontally. The soils have been mapped using high intensity sampling with a 55 m sampling grid (Figure 4-3, TABLE 4-3).[1] There are 19 soil types but the predominant soil types are loam, sandy loam, or loamy sand. Hydraulic limitations of the site vary from 0 to over 20 cm/week with the average limit being 5 cm/ha/week. Overall, these soils have

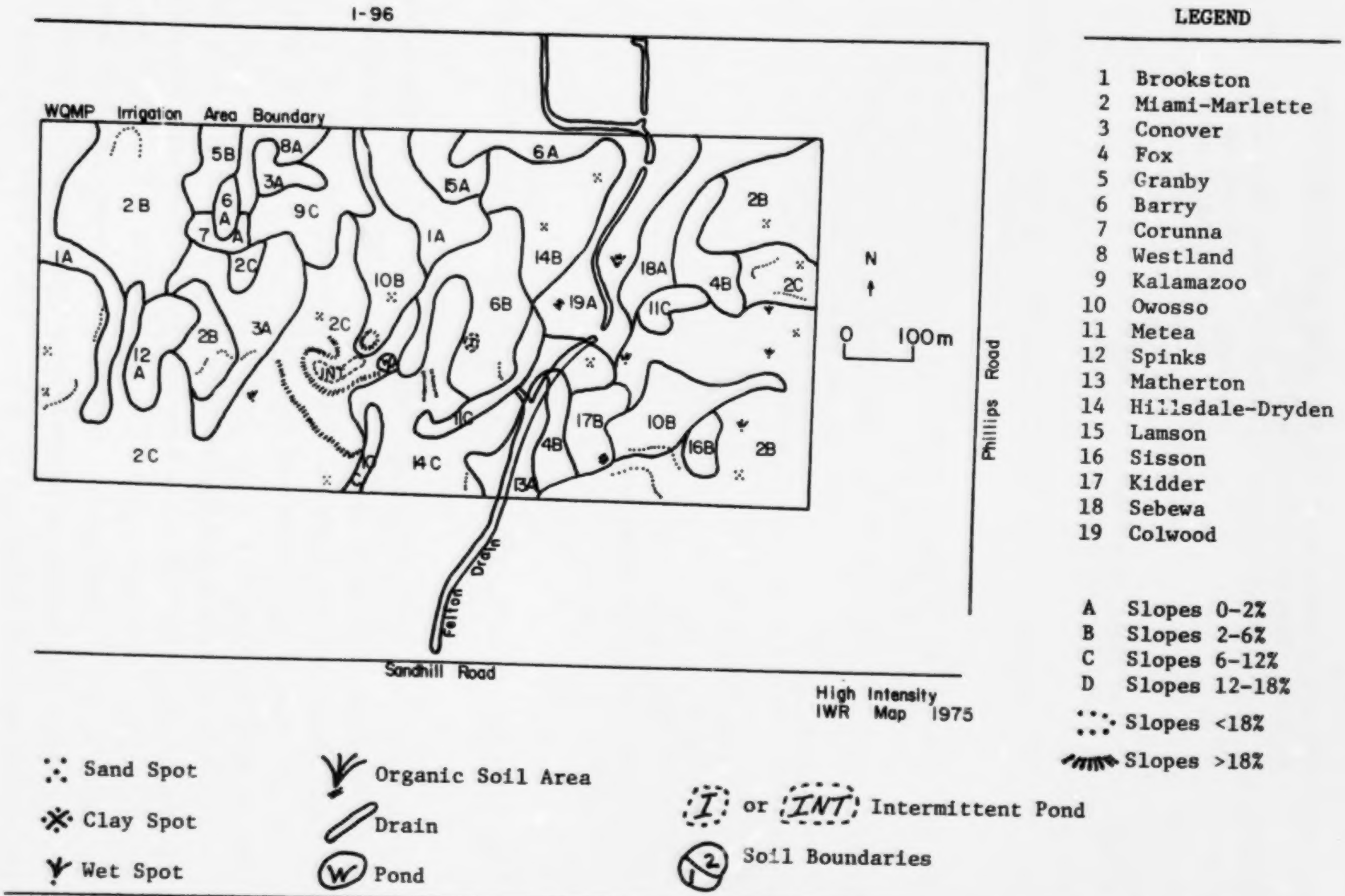
I-96
WQMP Irrigation Area Boundary
2B
5B
8A
3A
6 A
9C
7
A
2C
1A
12 A
2B
3A
2C
INT
10B
15A
1A
6A
14B
6B
19A
18A
11C
4B
2B
2C
N
0 100m
Phillips Road
11C
17B
10B
16B
2B
4B
14C
13A
10
2C
Felton Drain
Sandhill Road
High Intensity IWR Map 1975
LEGEND
1 Brookston
2 Miami-Marlette
3 Conover
4 Fox
5 Granby
6 Barry
7 Corunna
8 Westland
9 Kalamazoo
10 Owosso
11 Metea
12 Spinks
13 Matherton
14 Hillsdale-Dryden
15 Lamson
16 Sisson
17 Kidder
18 Sebewa
19 Colwood
A Slopes 0-2%
B Slopes 2-6%
C Slopes 6-12%
D Slopes 12-18%
Slopes <18%
Slopes >18%
Sand Spot
Clay Spot
Wet Spot
Organic Soil Area
Drain
Pond
I or INT Intermittent Pond
Soil Boundaries

Figure 4-3: Soil map of the spray irrigation site.

TABLE 4-3: GENERAL SOIL DESCRIPTION OF THE SPRAY IRRIGATION SITE

		GENERAL SOIL DESCRIPTION		
Map Symbol*	Soil Name	Surface Soil	Subsoil	Underlying Materials
1	Brookston	Loam	Clay loam	Loam to silt loam
2	Miami-Marlette	Loam	Clay loam	Loam to silt loam
3	Conover	Loam	Clay loam	Loam to silt loam
4	Fox	Loam	Gravelly clay loam to sandy clay loam	Sand and gravel
5	Granby	Loamy sand	Fine sand	Sand to fine sand
6	Barry	Sandy loam	Sandy clay loam	Sandy loam
7	Corunna	Sandy loam	Sandy loam	Loam to clay loam
8	Westland	Silty clay loam	Clay loam to gravelly clay loam	Gravel and sand
9	Kalamazoo	Loam	Gravelly clay loam to sandy clay loam	Sand and gravel
10	Owosso	Sandy loam	Sandy loam to sandy clay loam	Loam to clay loam
11	Metea	Loamy sand	Loamy sand to sand	Loam to clay loam
12	Spinks	Loamy sand	Loamy sand to sandy loam	Sand
13	Matherton	Loam	Gravelly loam to sandy clay loam	Sand and gravel
14	Hillsdale	Sandy loam	Sandy clay loam to sandy loam	Sandy loam to loamy sand
15	Lamson	Fine sandy loam	Fine sandy loam to silt loam	Fine sand to loamy very fine sand
16	Sisson	Fine sandy loam	Silt loam to silty clay loam	Very fine sands and silts
17	Kidder	Clay loam	Sandy clay loam	Gravelly sandy loam
18	Sebewa	Loam to sandy loam	Gravelly sandy clay loam to clay loam	Sand and Gravel
19	Colwood	Loam	Silt loam to silty clay loam	Very fine sands and silts

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* See Figure 4-2.

excellent phosphorus sorption capabilities. As calculated from the soils map and data given by Schneider and Erickson,[2] at least 1600 kg/ha of phosphorus could be sorbed by the first 0.9 m of soil without any vegetative removal. Thus, this site has infiltration and phosphorus sorption characteristics suitable for land application of wastewater.

GENERAL STUDY APPROACH

The spray irrigation site was intensively monitored for surface runoff at several points along the main drain and its tributaries (Figure 4-4). Water quality was monitored at stations UNFD 02, UNFD 10 (Felton Drain upstream and downstream of the spray site), at station UNFD 13 (output from the baseline watershed), at station UNFD 14 (output from forest sites), at station UNFD 04 (tile drain output from oldfield studies), and at UNFD 06 (output from the winter spray areas).

The conceptual basis for the monitoring approach to the Felton-Herron watershed study was shaped by the two types of hydrologic events experienced in this watershed. Events either resulted from natural processes (rain and snow melt) or from wastewater irrigation. Monitoring of runoff from individual irrigation sites (UNFD 04, UNFD 06, UNFD 13, UNFD 14 -- Figure 4-4) was expected to delineate specific source loadings from each type of wastewater irrigation management used (see Sections 5 to 9). These specific studies were to be coupled with studies of runoff from the main channel representing an integration of all loads from the site. The main channel Felton Drain studies included an input station, UNFD 02 (Figure 4-4), which drained an upstream 54 ha area of mixed crop and pasturelands plus runoff from a series of poultry barns which make up Michigan State University's Poultry Production/Research Station. Poultry manure from these barns was spread over the surrounding grounds as fertilizer resulting in high inputs to Felton Drain. The output station, UNFD 10 (Figure 4-4), included the actual spray irrigation site, part of its aerosol buffer zone, and runoff from a 36 ha area of an interstate highway, I-96.

The results from the main channel Felton Drain studies were not conclusive for the following reasons. First, the inputs to the site were high and very variable because of the manure spreading associated with the

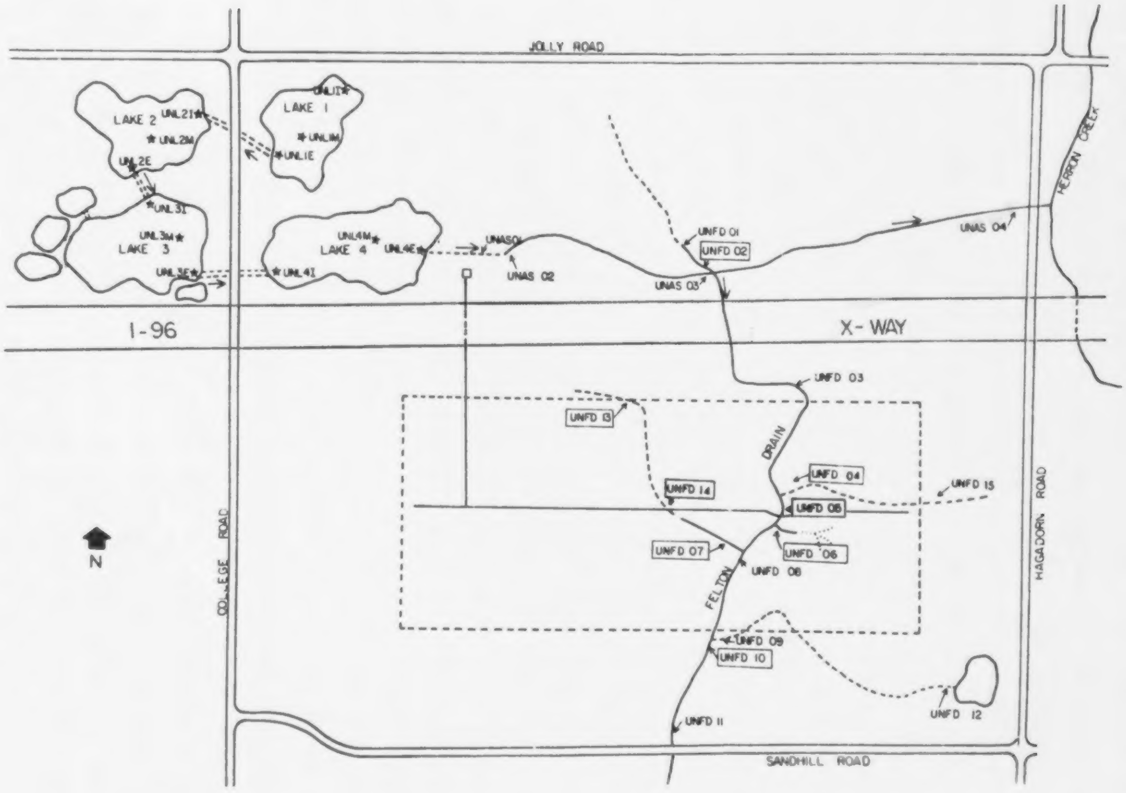
JOLLY ROAD
HERRON CREEK
LAKE 2
UNL2I
UNL2M
UNL2E
LAKE 1
UNL1I
UNL1M
UNL1E
UNL3I
UNL3M
LAKE 3
UNL3E
UNL4M
LAKE 4
UNL4E
UNL4I
UNAS01
UNAS 02
UNFD 01
UNFD 02
UNAS 03
UNAS 04
I-96
X-WAY
UNFD 03
UNFD 13
DRAIN
UNFD 04
UNFD 15
UNFD 14
UNFD 05
UNFD 07
UNFD 06
UNFD 08
FELTON
UNFD 09
UNFD 10
UNFD 11
UNFD 12
N
COLLEGE ROAD
HAGADORN ROAD
SANDHILL ROAD

Figure 4-4: Location and station designation of existing water quality monitoring points. Sampling stations enclosed by a rectangle denote location of recording stream gauging stations.

upstream poultry production/research facility. Second, the total area irrigated during this study (12.6 ha) was less than 15% of the 84 ha total area drained by the output station after inputs from the 54 ha upstream station were subtracted. Third, inputs from the 36 ha highway drainage area to the total 84 ha downstream area were not monitored and could have contributed substantial amounts of some constituents (e.g., chloride from winter salting operations). Fourth, the output from the 16 ha wastewater lake system of the Water Quality Management Facility was diverted down Felton Drain in August, 1976, before the first complete year of sampling was completed. Fifth, low flow samples were highly variable as a result of the various processes occurring in the watershed, resulting in large errors associated with low flow loadings. These large errors resulted from the relatively few low flow samples taken since event sampling was emphasized, and since concentrations of constituents in stream discharge were highly variable. Also, stream flow sometimes resulted from wastewater irrigation only, from lake discharge only, from rainfall generated runoff only, or from a combination of two or more of the preceeding. As a result of the many variables included in the main drain sampling program and as a result of the high errors associated with loading estimates of low flow from the output station, these studies did not result in useful data. Preliminary estimates for the input and output stations were included in the recent summary pilot watershed report.[3] They and runoff from the specific irrigation areas have been recalculated using the Beale ratio estimator technique adopted for IJC studies. Estimates were made for each season by treating the rising limb of each runoff event as one stratum, the falling limb as a second stratum, and each daily low flow sample as a stratum, then using these strata to estimate total seasonal loads. The non-event strata of the output station are characterized by large errors as discussed above. The input-output data for the main drain will not be presented here since they appear to be meaningless. They are available upon request from T.M. Burton. Runoff and groundwater recharge from specific wastewater management activities will be discussed in detail in the following sections (Sections 5 to 9). Precipitation inputs were also measured with rain gauges at sites in the center of the spray irrigation site and on the east and west ends of the site. These data are incorporated in the mass balances presented in the following sections (Sections 5 to 9).

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SECTION 5

LAND APPLICATION OF MUNICIPAL EFFLUENT ON OLDFIELDS AND ON GRASS LANDS

James E. Hook and Thomas M. Burton

INTRODUCTION

Land application can be a practical means of recycling the nutrients in municipal wastewaters if such systems are harvested. While wastewaters may be safely applied to non-harvested areas, such application must eventually result in a buildup of waste constituents until annual leaching, runoff or gaseous loss of those constituents equals annual application. Such sites may be successful if waste constituents are diluted by rainfall and groundwater to safe levels or if they are decomposed (e.g., organic matter, nitrate) to gaseous forms or if potential storage capacity is much higher than annual application rates thus assuring a reasonable life of the system.

Under most conditions, sustained use of a wastewater renovation site will require removal of some or all of the nutrients by plant harvest. To the operator of the waste application site, any harvest or other manipulation of the site represents an added expense. Justification for this additional manipulation of the site comes from a) direct return -- sale of feed or fiber products produced, b) indirect -- extension of the life of the renovation site and/or production of an environmentally acceptable or legally mandated water quality. These costs and returns are impossible to evaluate unless the interaction of various crops and cropping systems of various wastewaters and application methods and of various soils and hydraulic conditions are known or predictable. Seitz and Swanson,[1] Evans,[2] Melsted[3] and many others have pointed out that we do not now have the ability to predict very many of the alternatives in land application of wastewater. The very dilute nature of the nutrient source and the generally high irrigation rates of land application systems make it difficult to extend conventional agricultural fertilization and irrigation knowledge to these systems. Further, very little is known of the effects of cropping and wastewater irrigation on the quality of leachate and runoff. Only through integrated studies of wastewater irrigation-cropping and non-cropping systems will the parameters needed to make least cost predictions of renovating wastewaters be available.

In a previous study of oldfield irrigation, Hook and Kardos[4] showed that an unharvested oldfield could effectively lower nitrate concentrations when irrigated at 5.0 cm/week during the growing season. When the irrigation rate was increased to 7.5 cm/week, nitrate leached from the site at concentrations greater than 10 mg N/ℓ. By subsequently lowering the weekly rate back to 5.0 cm/week, the leachate concentration decreased to acceptable levels.[5] The effectiveness of this oldfield for N renovation was greater during the first eight years than for the last three years of the 14 years of effluent additions. This may have been due in part to lack of harvest since the vegetation had changed from an open oldfield with a few small trees to what more closely resembled an early successional forest.[6] When an effluent irrigated forest area was clear-cut, volunteer vegetation again proved effective in controlling nitrate leaching.[5]

Previous studies on grass fields irrigated with municipal effluent have usually dealt with harvested areas.[7-11] All have reported excellent retention of N and adequate removal in the harvested grass to prevent excessive nitrate leaching. The effectiveness of the grass under simple management schemes remains to be evaluated.

The purpose of this study, then, was to develop choices of vegetative management for land application systems. Specifically, it compared several methods of managing grasses and oldfield vegetation with respect to leaching of nitrate and other major nutrients.

MATERIALS AND METHODS

Site Description

The two different sets of experiments in this study included experiments on a planted grass site and experiments on volunteer oldfield vegetation. Vegetation on the planted site was 'Park' Kentucky bluegrass

(*Poa pratensis*, L.) established in 1973 and mowed periodically in 1974 and 1975. In 1976, twelve 10 x 10 m plots were established in four blocks of three cutting treatments each. The cutting treatments were: 1) harvest as hay three times annually, 2) mow biweekly leaving the vegetation on the site, and 3) no cutting. The plots had been irrigated with secondary municipal effluent at an average of 5.0 to 6.3 cm/week during the growing season of 1974 and 1975. They were irrigated at 7.5 cm/week (0.83 cm/hour for three hours, three days per week) from April 28, 1976 to October 8, 1976 and from May 11, 1977 to July 15, 1977. The soil at the site was a Miami loam, a member of the fine-loamy, mixed mesic family of Typic Hapludalfs, and was developed on silt to loam glacial till. The soil was well drained.

The second experimental site was an oldfield that had been abandoned from corn cultivation approximately 10 years earlier. The predominant vegetation on this site was *Solidago sp.*, *Agropyron repens*, *Aster sp.*, *Taraxacum officinale*, and *Poa compressa*. The site was divided into three irrigation treatment areas (0, 5, and 10 cm/week). The site had been irrigated with secondary municipal effluent in 1975. It was not harvested in 1975. In 1976, the previously irrigated areas were divided into four blocks for a complete block design. Each block contained six plots with randomly assigned treatments. These treatments were: irrigation rates of 5 and 10 cm/week; and cutting managements of zero, one (June) and two (June and September) harvests for each irrigation rate. In addition to the irrigated blocks, two non-irrigated control blocks of six plots each were established with the three cutting managements duplicated within each block. Each treatment plot was approximately 0.07 ha with a smaller area in the center of the plot used for monitoring nutrient changes in soil and soil-water. The irrigated plots were sprayed at 5.0 cm/week (0.83 cm/hour for three hours, two days per week) or at 10.0 cm/week (0.83 cm/hour for six hours, two days per week) with Buckner 8600 agricultural spray heads from April 19 to October 22, 1976, and from April 18 to October 27, 1977. The wastewater applied was a mixture of secondary effluent directly from East Lansing, Michigan or water that had back-siphoned from the first of four receiving lakes. Wastewater was chlorinated prior to application.

The soils at this oldfield site were the Miami silt loam described above and the Fox sandy loam, a member of fine-loamy over sandy or sandy skeletal, mixed, mesic family of Typic Hapludalfs. The Fox soil like the Miami was well drained. It was formed in loamy outwash overlying stratified calcareous sands and gravels.

Sampling and Analyses

Wastewater was sampled from each application with acid washed polyethylene funnel collectors placed 1.5 m above the ground. Soil-water was sampled using porous cup vacuum type tube lysimeters evacuated to 0.8 atmospheres immediately before one weekly irrigation and sampled 48 hours later. In the bluegrass site these lysimeters were placed with the cup at 15 and 150 cm below the surface and with small diameter tubing connecting the cup with the sample vacuum chamber located above ground. In the oldfield site, the lower cup and vacuum chamber were at the 120 cm depth.

No surface runoff was seen at either site when irrigated at the 0.83 cm/hour rate. There was some tile drainage from an existing tile system from the oldfield site. This tile drainage was sampled with an ISCO sequential sampler for a limited number of events in 1976. In 1977, events were sampled with the sequential sampler every other week; these samples were supplemented by 5-10 grab samples each week. Rainfall was measured in four recording rain gauges located within 1.2 km of the sites. Wastewater application was calculated from pumping records and was verified with 52 plastic rain gauges in the irrigated plots. Evapotranspiration and recharge were calculated using Thornthwaite and Mather's technique.[12]

Plant biomass was measured at two to four week intervals at both sites during the growing season. In the oldfield, four 0.25 m^2 quadrats were sampled in each plot. All vegetation above the ground surface was removed, sorted to species, segregated into living and litter components, dried in an oven at 70 C, weighed for biomass determination, then ground in a Wiley Mill and subsampled for subsequent tissue analysis of N and P. In the grass plots, three 0.25 m^2 quadrats were sampled in each plot. All vegetation standing above the normal cutting height (5 cm) in these grass plots was removed for biomass determination. In 1976, the quadrat samples in the oldfield were supplemented by yield estimates which were made by weighing all vegetation cut in a 0.84 x 9.1 m strip with a sickle bar mower. Yield data for 1976 agreed closely with biomass estimates made from the four quadrat samples; therefore, only quadrat data were used in 1977.

Nitrate and ammonium in all water and soil-water samples were determined by ion-selective electrodes[13,14] in 1976 and by distillation[15] in 1977. Kjeldahl-N was determined on monthly soil-water composites and on all effluent samples by semi-microkjeldahl digestion[16] followed by distillation. Chloride was determined by ion-selective electrode, Na and K were determined by emission spectroscopy, and Ca and Mg were analyzed by atomic absorption. Oldfield plant samples were analyzed for Kjeldahl plus nitrate N by semi-microkjeldahl digestion[17] followed either by NH_3 determination by ammonium electrode or by distillation. Total plant P was measured in the microkjeldahl digest by the vanadomolybdophosphoric acid colorimetric method.[18] Soil samples were analyzed for nitrate, ammonium, and chloride extracted from wet samples with $1\underline{N}$ K_2SO_4 (approximately a 1:5 soil:solution ratio)[19]; for Na, K, Ca, and Mg extracted with $1\underline{N}$ NH_4OAc (1:8 soil:solution ratio)[20]; and for available P extracted with dilute acid-fluoride (1:8 soil:solution ratio)[21] and analyzed by the colorimetric method.[22]

RESULTS AND DISCUSSION

Bluegrass Cutting Management

The major nutrients added in 1976 and 1977 (TABLE 5-1) were made in approximately equal, weekly increments throughout the growing season. Based upon total annual loadings, no nutrients should be limiting for growth of bluegrass.

The growth of the bluegrass increased with cutting. The dry weight of new biomass above the cutting height (5 cm) increased from an average of 20.8 kg/ha/day with no cutting to 34.2 and 44.9 kg/ha/day with hay harvest and mowing, respectively, during 1976. The increase in rate of growth should have been accompanied by an increase in the rate of nutrient uptake resulting in a decreased probability that nutrients in wastewater would leach past the root zone.

TABLE 5-1. MEAN ANNUAL CONCENTRATION AND TOTAL AMOUNTS OF WASTEWATER CONSTITUENTS APPLIED TO THE GRASS MANAGEMENT SITE FROM 7.5 cm/WEEK OF WASTEWATER IRRIGATION

	Effluent Concentrations (mg/ℓ)		Amount Applied (kg/ha)	
	1976	1977	1976	1977
NO_3-N	12.11	8.50	214	153
NH_4-N	1.68	1.51	30	27
Total N	15.30	11.72	272	211
Total P	2.68	2.72	48	49
K	10.4	10.4	189	187
Ca	79.7	57.6	1363	1037
Mg	25.8	25.3	449	455
Na	88.8	98.3	1566	1769

The amounts of nitrate in soil-water both in the root zone and below, however, varied little with cutting or with time of year (Figures 5-1 and 5-2). Mineral N, nearly all nitrate, in both the root zone and at the 150 cm depth consistently remained below 10 mg N/ℓ. Despite the fact that no vegetation was removed from the no-cutting and the mowing plots, these plots were as effective as the harvested plots in controlling N leaching past the 150 cm depth.

The effectiveness of the no harvest plots can be explained by denitrification and by immobilization of N in plant materials. The latter appears unlikely in the case of mowed plots because the plant residues which fall to the ground are rapidly incorporated and are likely mineralized as well.

On the other hand, denitrification has been observed under rapidly growing grasses.[23] Production of root exudates and decomposing organic material could supply carbon for denitrification. Root respiration and high moisture content due to the irrigation favors lowered oxygen content. These conditions should be greatest in the mowed plots, because the average biomass production rate was greatest and because all the residues were left on the plot to decompose. The no-cut grass plots had the lowest average

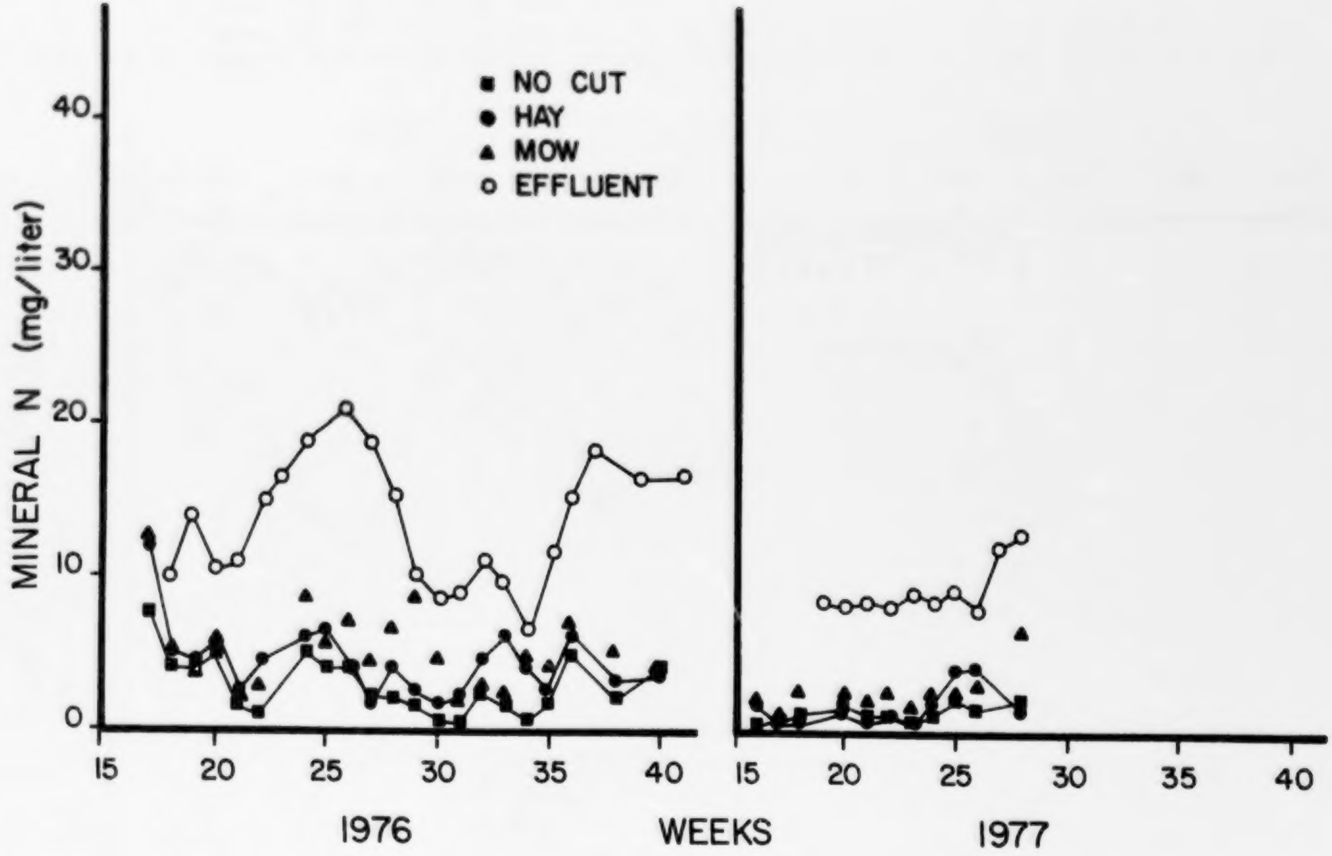

Figure 5-1: Weekly average mineral N concentrations in applied effluent and in soil-water from the 15 cm depth of the 7.5 cm/week irrigation rate on bluegrass managed with various cutting treatments.

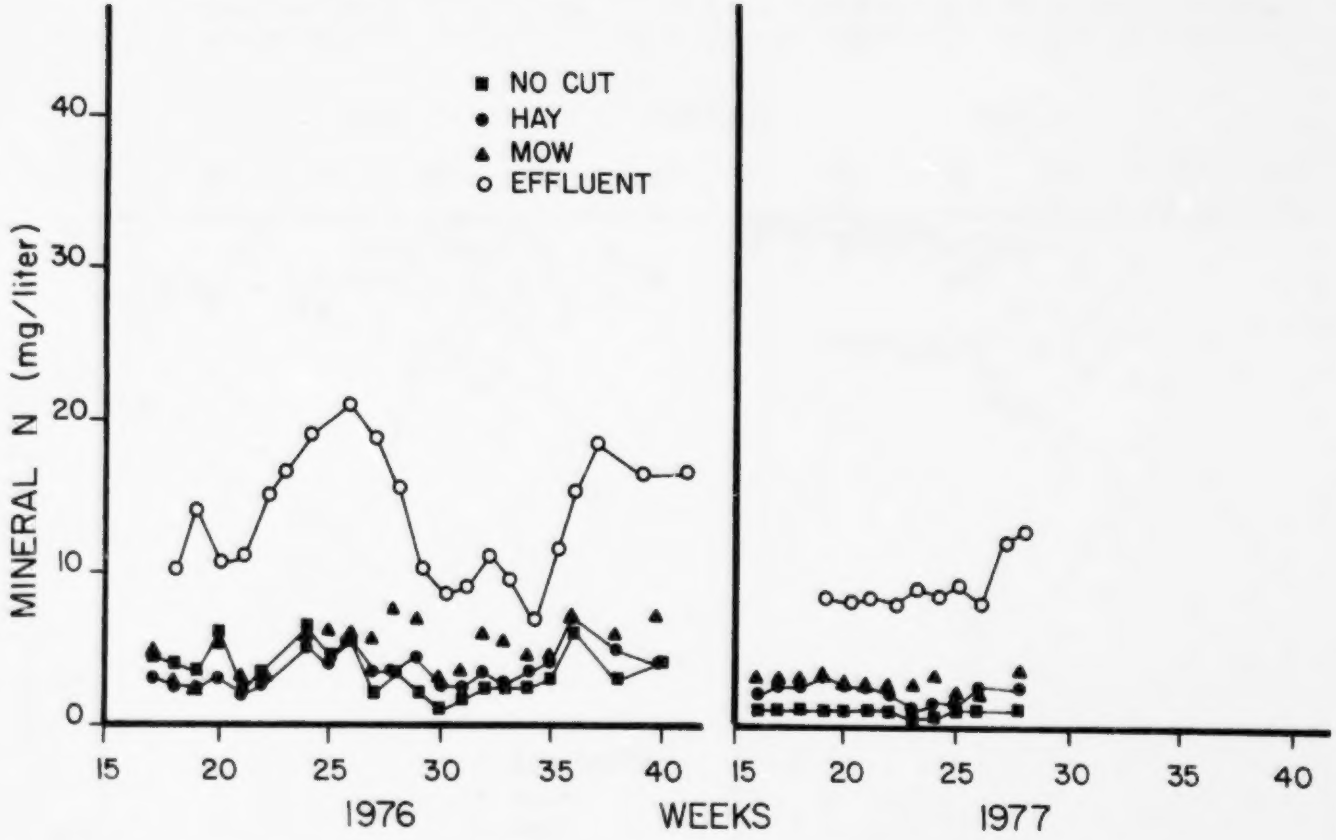

Figure 5-2: Weekly average mineral N concentrations in applied effluent and in soil-water from the 150 cm depth of the 7.5 cm/week irrigation rate on bluegrass managed with various cutting treatments.

annual production rate. However, the productivity during the first three months (4/27-7/13) of the growing season was similar to that of harvested plots at 54.3 kg/ha/day. After mid-July, productivity declined, and the amount of biomass present actually declined. As productivity slowed and biomass declined and as plants decomposed, a mineralization-nitrification-denitrification sequence may have prevented nitrate leaching.

Oldfield Cutting Management

The concentrations as well as the amounts of wastewater constituents added to this site are given in TABLE 5-2. Most constituents were added uniformly throughout the irrigation period. However, monthly N concentrations fluctuated as much as two-fold. This occurred because approximately 80% of the wastewater applied weekly was backsiphoned from the first of the effluent treatment lakes rather than from the effluent pipeline. This backsiphoned water was thus subject to the N dynamics of the lake.

TABLE 5-2. MEAN ANNUAL CONCENTRATION AND TOTAL AMOUNTS OF WASTEWATER CONSTITUENTS APPLIED TO THE IRRIGATED AREAS OF THE OLD FIELD SITE

	Effluent Concentrations (mg/ℓ)		Amount Applied (kg/ha) 5 cm/week		Amount Applied (kg/ha) 10 cm/week	
	1976	1977	1976	1977	1976	1977
NO_3-N	10.49	9.14	127	122	224	232
NH_4-N	1.35	1.23	16	16	30	31
Total N	13.66	13.61	167	182	329	346
Total P	2.72	2.74	33	37	66	70
K	9.98	10.50	117	141	244	267
Ca	69.85	57.89	849	776	1700	1470
Mg	24.38	25.55	290	342	596	649
Na	86.47	97.11	1024	1301	2119	2467

As expected, the effluent irrigation increased dry matter production of the harvested plots (TABLE 5-3). The N and P concentrations of the plant tissue were also increased by irrigation at both the 5 and 10 cm/week levels. Harvest of the vegetation in September as well as in June increased the average annual total biomass removal by 78, 46, and 47% for the 0, 5, and 10 cm/week irrigations, respectively. This second harvest was also responsible for increasing the N removal by 76, 39, and 57%, respectively, for the three irrigation rates (TABLE 5-3).

Nitrogen--

The effectiveness of the various treatments for controlling N leaching can be seen by the annual N balances which were calculated for the 1976-1977 water year (TABLES 5-4 to 5-6). When irrigated at 5 cm/week, the amount of mineral N which leached past the 120 cm depth was less than 20% of the added mineral N regardless of the harvest management used. When the weekly irrigation rate was increased to 10 cm/week (TABLE 5-6), the mineral N which leached to the 120 cm depth made up 42, 26, and 31% of the added N for the zero, one and two annual harvests. The harvests, either once or twice, lowered the amount of N leaching by about 35% compared to the unharvested treatment for this 10 cm/week rate.

The effectiveness of the oldfield vegetation, like the bluegrass vegetation, can be explained in terms of the rapidly growing vegetation which both immobilizes added mineral N and stimulates denitrification. The plots harvested once during the year were harvested in June when growth rate and total biomass were maximal. This biomass removed 77% of the N added to the 5 cm/week plots and 52% of the N added to the 10 cm/week plots. The second harvests remove biomass when the regrowth is maximal. The two harvest management removed 94% and 83% of the N added to the 5 and 10 cm/week plots, respectively. Thus, while the single harvest did an adequate job of removing effluent N, two harvests assured that N would neither build up at the site nor leach to the groundwater.

The unharvested plots on an annual mass balance basis, also proved effective in preventing N leaching, particularly at the 5 cm/week level. A possible explanation is denitrification occurring subsequent to maximum

TABLE 5-3. MEAN ANNUAL YIELD, N AND P CONTENT AND N AND P REMOVALS OF THE HARVESTED PLOTS OF THE OLDFIELD SITE

Irrigation Rate	Harvest		Yield Dry Weight Metric tons/ha	Nitrogen Content* % Dry Weight	Nitrogen Removal kg/ha	Phosphorus Content* % Dry Weight	Phosphorus Removal kg/ha
0 cm/week	One Cut	1976	3.16	1.94	61	0.30	9.5
		1977	2.30	1.61	37	0.28	6.5
		Average	2.73	1.78	49	0.29	8.0
	Two Cuts	1976	5.24	1.93	101	0.30	15.6
		1977	4.49	1.56	70	0.27	12.0
		Average	4.87	1.75	86	0.29	13.8
5 cm/week	One Cut	1976	4.50	2.15	97	0.32	14.4
		1977	6.73	1.90	128	0.31	21.1
		Average	5.62	2.03	113	0.32	17.8
	Two Cuts	1976	7.59	2.08	157	0.32	24.2
		1977	8.76	1.78	156	0.33	29.1
		Average	8.18	1.93	157	0.33	26.7
10 cm/week	One Cut	1976	5.18	2.38	123	0.37	19.2
		1977	8.08	1.82	147	0.28	22.6
		Average	6.63	2.10	135	0.33	20.9
	Two Cuts	1976	7.88	2.36	187	0.34	26.9
		1977	11.65	2.03	237	0.34	39.7
		Average	9.76	2.20	212	0.34	33.3

* For the two cutting management these are weighted average content.

TABLE 5-4. MASS BALANCE FOR INORGANIC N FOR THE 0 cm/WEEK OLDFIELD SITE (VALUES IN kg N/ha)

	INPUT			OUTPUT		
Month	Precipitation	Irrigation	Total	Vegetation Removal	Recharge	Retention
			**** NO	HARVEST	****	
Oct 76	1.52	0	1.52	0	0.00	1.52
Nov 76	0.59	0	0.59	0	0.00	0.59
Dec 76	0.38	0	0.38	0	0.00	0.38
Jan 77	0.28	0	0.28	0	0.00	0.28
Feb 77	4.65	0	4.65	0	0.00	4.65
Mar 77	2.05	0	2.05	0	0.00	2.05
Apr 77	3.00	0	3.00	0	0.25	2.75
May 77	0.36	0	0.36	0	0.00	0.36
June 77	3.01	0	3.01	0	0.00	3.01
July 77	1.29	0	1.29	0	0.00	1.29
Aug 77	1.77	0	1.77	0	0.00	1.77
Sep 77	3.35	0	3.35	0	0.00	3.35
ANNUAL	22.25	0	22.25	0	0.25	22.00
% Input	100.00	0	100.00	0	1.00	99.00
			**** ONE	HARVEST	****	
Oct 76	1.52	0	1.52	0	0.00	1.52
Nov 76	0.59	0	0.59	0	0.00	0.59
Dec 76	0.38	0	0.38	0	0.00	0.38
Jan 77	0.28	0	0.28	0	0.00	0.28
Feb 77	4.65	0	4.65	0	0.00	4.65
Mar 77	2.05	0	2.05	0	0.00	2.05
Apr 77	3.00	0	3.00	0	0.14	2.86
May 77	0.36	0	0.36	0	0.00	0.36
June 77	3.01	0	3.01	37	0.00	-33.99
July 77	1.29	0	1.29	0	0.00	1.29
Aug 77	1.77	0	1.77	0	0.00	1.77
Sep 77	3.35	0	3.35	0	0.00	3.35
ANNUAL	22.25	0	22.25	37	0.14	-14.89
% Input	100.00	0	100.00	166	1.00	-67.00
			**** TWO	HARVESTS	****	
Oct 76	1.52	0	1.52	0	0.00	1.52
Nov 76	0.59	0	0.59	0	0.00	0.59
Dec 76	0.38	0	0.38	0	0.00	0.38
Jan 77	0.28	0	0.28	0	0.00	0.28
Feb 77	4.65	0	4.65	0	0.00	4.65
Mar 77	2.05	0	2.05	0	0.00	2.05
Apr 77	3.00	0	3.00	0	0.19	2.81
May 77	0.36	0	0.36	0	0.00	0.36
June 77	3.01	0	3.01	42	0.00	-38.99
July 77	1.29	0	1.29	0	0.00	1.29
Aug 77	1.77	0	1.77	0	0.00	1.77
Sep 77	3.35	0	3.35	28	0.00	-24.65
ANNUAL	22.25	0	22.25	70	0.19	-47.94
% Input	100.00	0	100.00	315	1.00	-215.00

TABLE 5-5. MASS BALANCE FOR INORGANIC N FOR THE 5 cm/WEEK OLDFIELD SITE (VALUES IN kg N/ha)

	INPUT			OUTPUT		
Month	Precipitation	Irrigation	Total	Vegetation Removal	Recharge	Retention
**** NO HARVEST ****						
Oct 76	1.52	25.97	27.49	0	7.02	20.47
Nov 76	0.59	0.00	0.59	0	0.94	-0.35
Dec 76	0.38	0.00	0.38	0	0.54	-0.16
Jan 77	0.28	0.00	0.28	0	0.35	-0.07
Feb 77	4.65	0.00	4.65	0	0.50	4.15
Mar 77	2.05	0.00	2.05	0	1.35	0.70
Apr 77	3.00	13.13	16.13	0	3.32	12.81
May 77	0.36	17.94	18.30	0	0.98	17.32
June 77	3.01	15.42	18.43	0	0.30	18.13
July 77	1.29	25.79	27.08	0	1.00	26.08
Aug 77	1.77	26.26	28.03	0	1.44	26.59
Sep 77	3.35	21.51	24.86	0	11.10	13.76
ANNUAL	22.25	146.02	168.27	0	28.84	139.43
% Input	13.00	87.00	100.00	0	17.00	83.00
**** ONE HARVEST ****						
Oct 76	1.52	25.97	27.49	0	6.12	21.37
Nov 76	0.59	0.00	0.59	0	0.67	-0.08
Dec 76	0.38	0.00	0.38	0	0.39	-0.01
Jan 77	0.28	0.00	0.28	0	0.26	0.02
Feb 77	4.65	0.00	4.65	0	0.38	4.27
Mar 77	2.05	0.00	2.05	0	1.11	0.94
Apr 77	3.00	13.13	16.13	0	2.91	13.22
May 77	0.36	17.94	18.30	0	1.75	16.55
June 77	3.01	15.42	18.43	128	1.54	-111.11
July 77	1.29	25.79	27.08	0	2.91	24.17
Aug 77	1.77	26.26	28.03	0	5.47	22.56
Sep 77	3.35	21.51	24.86	0	6.68	18.18
ANNUAL	22.25	146.02	168.27	128	30.19	10.08
% Input	13.00	87.00	100.00	77	18.00	6.00
**** TWO HARVESTS ****						
Oct 76	1.52	25.97	27.49	0	2.03	25.46
Nov 76	0.59	0.00	0.59	0	0.83	-0.25
Dec 76	0.38	0.00	0.38	0	0.43	-0.05
Jan 77	0.28	0.00	0.28	0	0.25	0.03
Feb 77	4.65	0.00	4.65	0	0.31	4.34
Mar 77	2.05	0.00	2.05	0	0.59	1.46
Apr 77	3.00	13.13	16.13	0	0.65	15.48
May 77	0.36	17.94	18.30	0	0.66	17.64
June 77	3.01	15.42	18.43	75	0.31	-56.88
July 77	1.29	25.79	27.08	0	1.08	26.00
Aug 77	1.77	26.26	28.03	0	1.51	26.53
Sep 77	3.35	21.51	24.86	81	1.52	-57.66
ANNUAL	22.25	146.02	168.27	156	10.17	2.10
% Input	13.00	87.00	100.00	93	6.00	1.00

TABLE 5-6. MASS BALANCE FOR INORGANIC N FOR THE 10 cm/WEEK OLDFIELD SITE (VALUES IN kg N/ha)

	INPUT			OUTPUT		
Month	Precipitation	Irrigation	Total	Vegetation Removal	Recharge	Retention
			**** NO HARVEST ****			
Oct 76	1.52	49.69	51.21	0	35.7	15.51
Nov 76	0.59	0	0.59	0	1.6	-1.01
Dec 76	0.38	0	0.38	0	1.0	-0.62
Jan 77	0.28	0	0.28	0	0.7	-0.42
Feb 77	4.65	0	4.65	0	1.0	3.65
Mar 77	2.05	0	2.05	0	3.2	-1.15
Apr 77	3.00	17.99	20.99	0	14.0	6.99
May 77	0.36	33.33	33.69	0	9.1	24.59
June 77	3.01	26.19	29.20	0	2.3	26.90
July 77	1.29	51.49	52.78	0	7.3	45.48
Aug 77	1.77	44.62	46.39	0	10.8	35.59
Sep 77	3.35	39.81	43.16	0	32.5	10.66
ANNUAL	22.25	263.12	285.37	0	119.2	166.17
% Input	8.00	92.00	100.00	0	42.0	58.00
			**** ONE HARVEST ****			
Oct 76	1.52	49.69	51.21	0	15.2	36.01
Nov 76	0.59	0	0.59	0	1.2	-0.61
Dec 76	0.38	0	0.38	0	0.7	-0.32
Jan 77	0.28	0	0.28	0	0.5	-0.22
Feb 77	4.65	0	4.65	0	0.7	3.95
Mar 77	2.05	0	2.05	0	2.2	-0.15
Apr 77	3.00	17.99	20.99	0	9.8	11.19
May 77	0.36	33.33	33.69	0	4.2	29.49
June 77	3.01	26.19	29.20	147	2.3	-120.10
July 77	1.29	51.49	52.78	0	6.4	46.38
Aug 77	1.77	44.62	46.39	0	8.6	37.79
Sep 77	3.35	39.81	43.16	0	24.0	19.16
ANNUAL	22.25	263.12	285.37	147	75.8	62.50
% Input	8.00	92.00	100.00	52	27.0	22.00
			**** TWO HARVESTS ****			
Oct 76	1.52	49.69	51.21	0	24.4	26.81
Nov 76	0.59	0	0.59	0	1.2	-0.61
Dec 76	0.38	0	0.38	0	0.7	-0.32
Jan 77	0.28	0	0.28	0	0.4	-0.12
Feb 77	4.65	0	4.65	0	0.5	4.15
Mar 77	2.05	0	2.05	0	0.8	1.25
Apr 77	3.00	17.99	20.99	0	3.8	17.19
May 77	0.36	33.33	33.69	0	2.9	30.79
June 77	3.01	26.19	29.20	125	2.0	-97.80
July 77	1.29	51.49	52.78	0	7.7	45.08
Aug 77	1.77	44.62	46.39	0	12.1	35.29
Sep 77	3.35	39.81	43.16	112	30.6	-99.44
ANNUAL	22.25	263.12	285.37	237	87.1	-38.73
% Input	8.00	92.00	100.00	83	31.0	-14.00

growth rate. Growth rate of the vegetation during the period May 1 to August 1, 1977 (weeks 17 to 30) was approximately 120 kg/ha/day. During this period 220 kg N/ha would be taken up by plants containing 2% N. This was higher than effluent N additions of 114 and 155 kg N/ha of the 5 and 10 cm/week rates. The additional N taken up would have to be supplied by mineralization of the litter remaining from the previous year's treatment and of native soil N. During this period, uptake can explain the low rate of N leaching. After August 1, the growth rate of the annuals drops sharply and net live biomass decreases. During this period, N needed for flowering and seed filling could be supplied from within the plant. As lower leaves drop off and decay, net additions of effluent and mineralized N must far exceed the plant needs. During this period, denitrification would probably have to occur to prevent excessive N leaching. Evidence for denitrification is uncertain. The concentration of mineral N in soil-water under the no harvest plots increases after about week 30, first in the topsoil (Figures 5-3 and 5-4) then in the subsoil (Figures 5-5 and 5-6). During this August to October period, unharvested plots were less effective than harvested plots, yet the annual mass balance indicates that 58 to 83% of the added N was either lost by denitrification or retained in the soil-plant system.

Organic plus ammonium N was monitored in soil-water samples during 1976 (TABLE 5-7). There were no significant differences in concentrations with either irrigation levels or irrigation managements. There was a slight decrease with depth.

Phosphorus--

Orthophosphate in the soil-water was also measured during 1976 (TABLE 5-8). Variability was very high in samples taken from the topsoil, particularly in the 10 cm/week plots. No significant differences were seen with treatments. In soil-water from the 120 cm depth, orthophosphate concentrations were at background concentrations. Given the fine texture of this soil and the annual loading rates, it was unlikely that the phosphorus concentrations would increase at this depth within the three years of effluent additions. Retention of phosphorus, based on the mass balance for

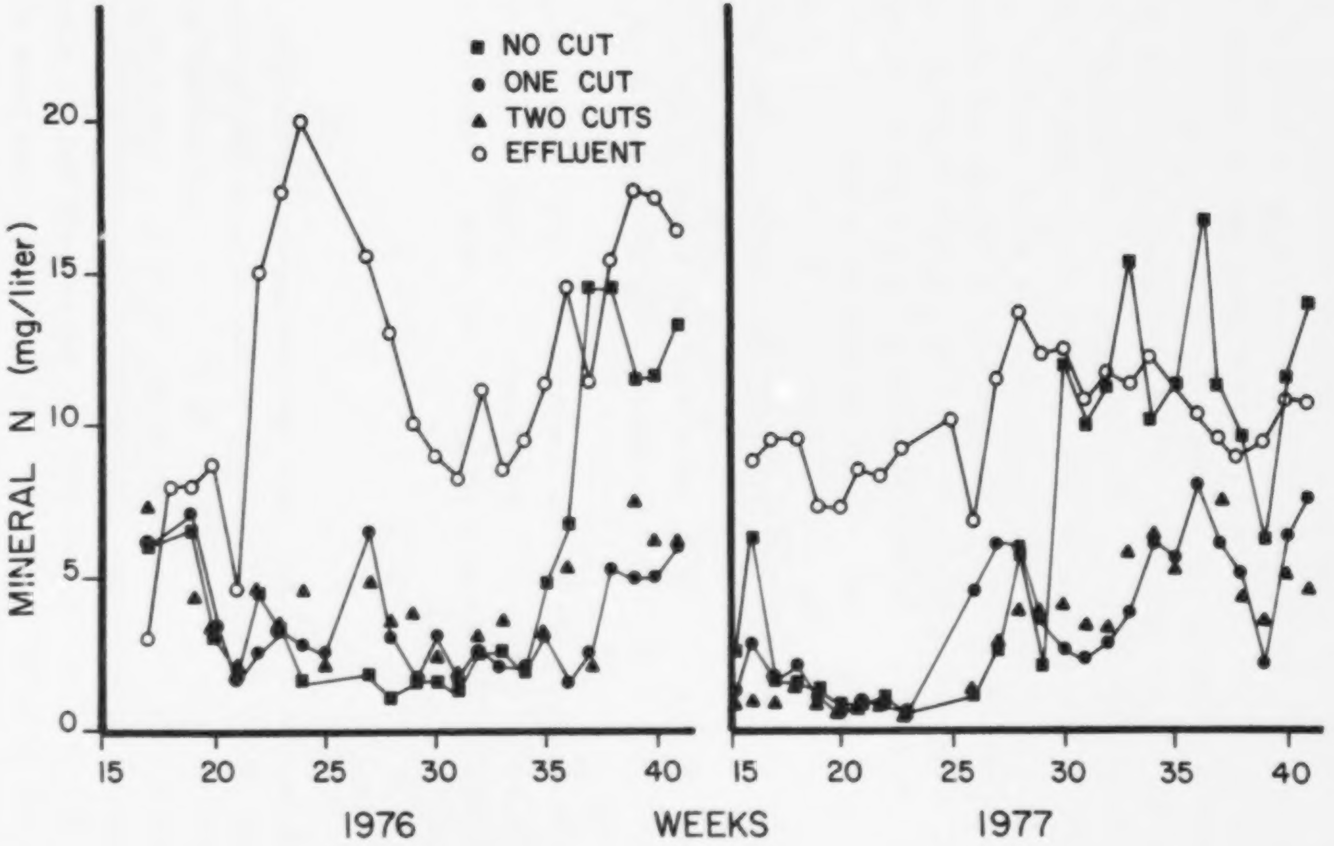

Figure 5-3: Weekly average mineral N concentrations in applied effluent and in soil-water from the 15 cm depth of the 5 cm/week irrigation rate on the oldfield wastewater irrigation site for various cutting treatments.

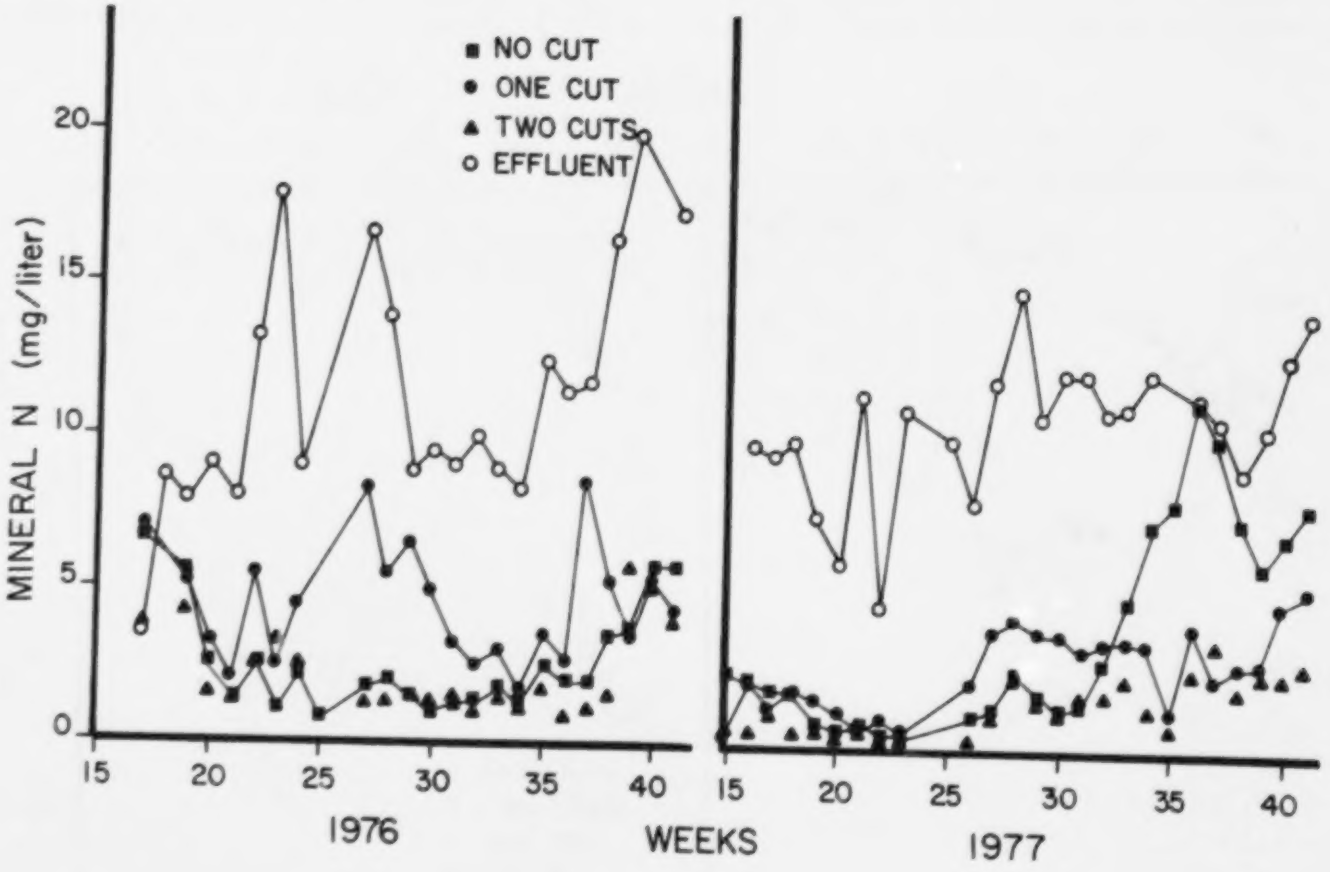

Figure 5-4: Weekly average mineral N concentrations in applied effluent and in soil-water from the 15 cm depth of the 10 cm/week irrigation rate on the oldfield wastewater irrigation site for various cutting treatments.

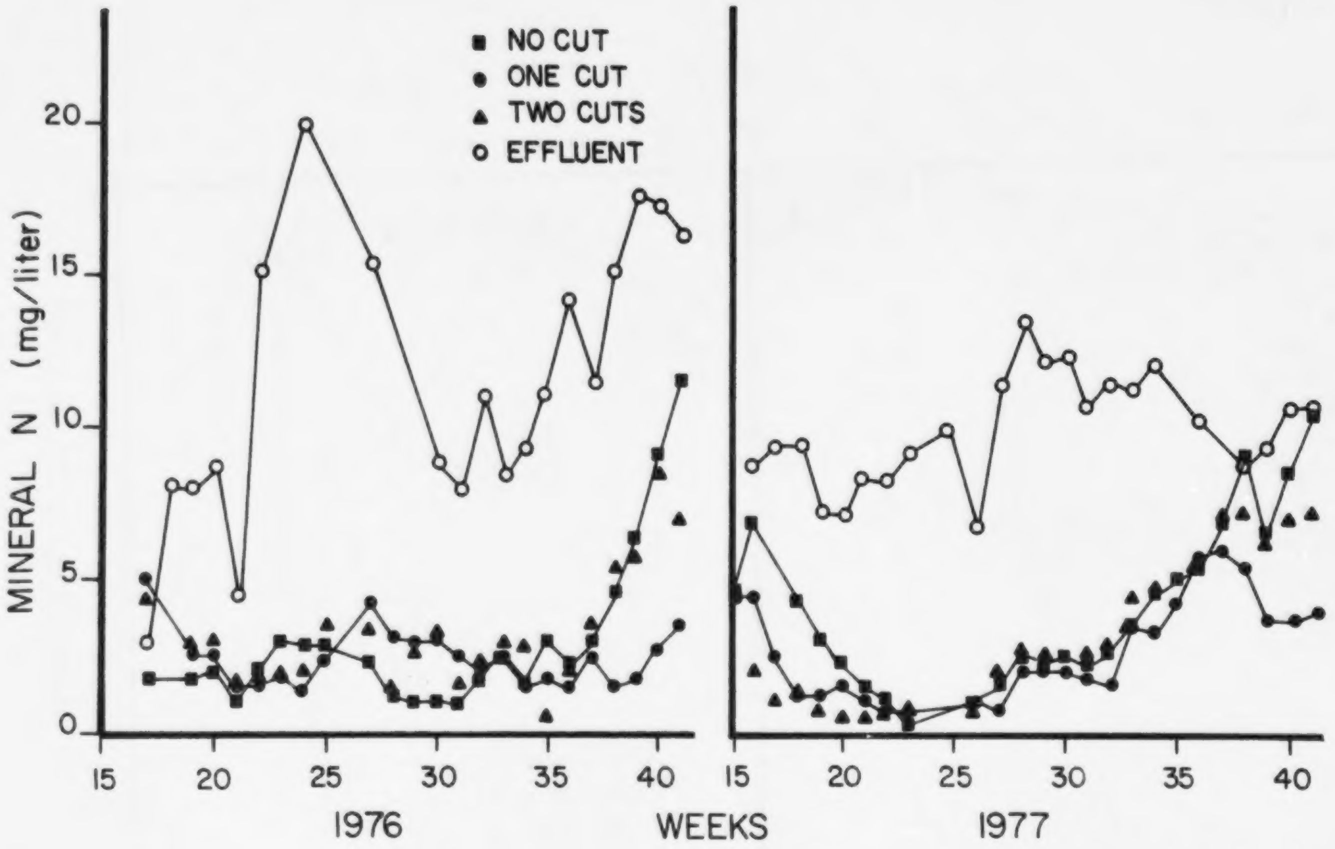

Figure 5-5: Weekly average mineral N concentrations in applied effluent and in soil-water from the 120 cm depth of the 5 cm/week irrigation rate on the oldfield wastewater irrigation site for various cutting treatments.

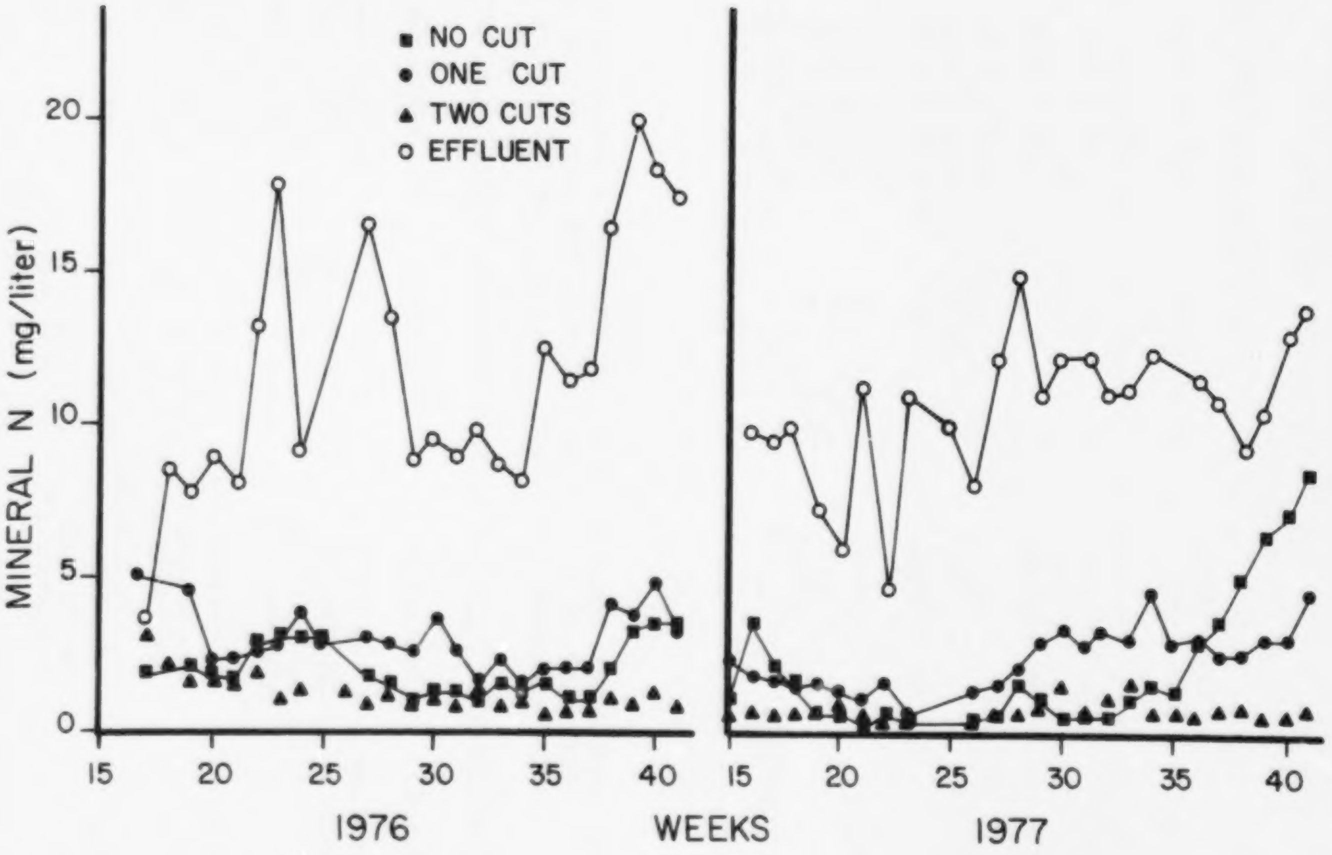

Figure 5-6: Weekly average mineral N concentrations in applied effluent and in soil-water from the 120 cm depth of the 10 cm/week irrigation rate on the oldfield wastewater irrigation site for various cutting treatments.

TABLE 5-7. MEAN ANNUAL ORGANIC PLUS AMMONIA NITROGEN CONCENTRATION IN SOIL-WATER SAMPLES TAKEN FROM THE TOPSOIL AND FROM BELOW THE ROOT ZONE OF THE OLDFIELD WASTEWATER IRRIGATION SITE, 1976 (VALUES IN mg N/ℓ ± one std. dev.)

Irrigation Rate	Vegetation Management	15 cm Depth	120 cm Depth
0.0 cm/week	No Cutting	*	1.24 ± 0.74
	One Cutting	*	*
	Two Cuttings	*	1.36 ± 0.66
5.0 cm/week	No Cutting	1.51 ± 0.49	0.87 ± 0.77
	One Cutting	1.91 ± 1.14	1.16 ± 1.11
	Two Cuttings	1.57 ± 0.57	1.05 ± 1.25
10.0 cm/week	No Cutting	1.58 ± 1.30	1.02 ± 0.82
	One Cutting	1.71 ± 0.70	0.99 ± 0.86
	Two Cuttings	1.68 ± 1.05	0.85 ± 0.63

* Insufficient number of samples to compute an average.

TABLE 5-8. MEAN ANNUAL ORTHOPHOSPHATE CONCENTRATION IN SOIL-WATER SAMPLES TAKEN FROM THE TOPSOIL AND FROM BELOW THE ROOT ZONE OF THE OLDFIELD IRRIGATION SITE, 1976 (VALUES IN mg P/ℓ ± one std. dev.)

Irrigation Rate	Vegetation Management	15 cm Depth	120 cm Depth
0.0 cm/week	No Cutting	.150 ± .130	.020 ± .010
	One Cutting	.100 ± .110	*
	Two Cuttings	.240 ± .280	.022 ± .008
5.0 cm/week	No Cutting	.072 ± .109	.032 ± .079
	One Cutting	.128 ± .166	.036 ± .110
	Two Cuttings	.048 ± .102	.015 ± .017
10 cm/week	No Cutting	.282 ± .635	.023 ± .031
	One Cutting	.238 ± .402	.028 ± .042
	Two Cuttings	.088 ± .083	.021 ± .029

* Insufficient samples to establish an annual mean.

1976, was very high (TABLE 5-9). While the soil-plant system effectively immobilized added phosphorus, the one and two harvest managements removed significant portions of the added P. This removal of P in harvest should significantly extend the sorption capacity of the system resulting in prolonged usefulness of the site. With continued additions and crop removals at the 1976 rates, accumulations of P on the site would occur at a rate three and one-half times faster for the no harvest treatment than for the two harvest treatment. Thus, the principle role of the harvest with respect to P was to extend the life of the land treatment system for P removal.

TABLE 5-9. PHOSPHORUS MASS BALANCE FOR 1976 FOR THE VARIOUS TREATMENTS OF THE OLDFIELD SITE (VALUES IN kg P/ha)

Irrigation Rate	Management	Effluent Input	Crop Removal	Recharge	Retained
0 cm/week	No Cut	0.0	0.0	0.01	0.0
	One Cut	0.0	9.5	0.01	-9.5
	Two Cuts	0.0	15.6	0.01	-15.6
5 cm/week	No Cut	33.3	0.0	0.40	32.9
	One Cut	33.3	14.4	0.45	18.5
	Two Cuts	33.3	24.2	0.19	8.9
10 cm/week	No Cut	65.8	0.0	0.55	65.3
	One Cut	65.8	19.2	0.67	45.9
	Two Cuts	65.8	26.9	0.51	38.4

Soil Samples

Soil samples were taken in the vicinity of the tube lysimeter sites in spring of 1976 and fall of 1976 and were analyzed for major nutrients and salts (TABLES 5-10 to 5-16). The relatively minor changes expected were largely masked by the large amounts of these elements already in the soil and by the inherent variability of the soil. The increases in exchangeable sodium and extractable chloride were the only observable changes associated with the effluent treatments. Neither presented a water quality or soil structural problem at observed levels (TABLES 5-10 to 5-16).

TABLE 5-10. BRAY EXTRACTABLE PHOSPHORUS ANALYSES OF SOILS FOR THE OLDFIELD WASTEWATER IRRIGATION STUDY (VALUES IN μg/g DRY SOIL)

	0 cm/week		5 cm/week		10 cm/week	
Depth (cm)	1975	1976	1975	1976	1975	1976
NO CUTTING MANAGEMENT						
0- 15	26.5	25.6	12.5	17.6	24.8	25.1
15- 30	10.9	10.6	4.9	4.4	9.7	9.8
30- 45	4.0	5.5	3.6	2.0	3.2	3.9
45- 60	4.7	3.7	3.4	2.3	3.7	4.4
60- 75	4.8	2.5	1.6	2.5	2.8	3.3
75- 90	2.8	1.6	1.3	1.9	3.1	2.8
90-105	2.7	1.8	2.7	1.8	1.9	1.9
105-120	2.5	2.8	1.0	1.1	1.8	2.0
Average	7.3	6.8	3.9	4.2	6.3	6.7
ONE CUTTING MANAGEMENT						
0- 15	43.4	37.7	58.9	26.6	34.0	33.9
15- 30	13.1	18.8	16.5	8.4	15.3	11.7
30- 45	4.1	5.4	12.8	8.4	11.8	10.6
45- 60	3.8	4.8	20.7	10.1	9.1	12.8
60- 75	3.5	4.9	10.9	5.5	4.7	12.0
75- 90	3.7	3.3	18.7	5.7	7.3	10.0
90-105	1.9	1.8	7.9	4.1	7.7	4.7
105-120	2.4	1.2	6.6	4.5	7.2	9.2
Average	9.5	9.7	19.1	9.2	12.1	13.1
TWO CUTTING MANAGEMENTS						
0- 15	41.8	25.1	22.2	16.1	24.3	29.9
15- 30	11.9	12.0	16.7	7.2	6.9	10.8
30- 45	14.4	6.0	4.5	2.4	17.2	4.4
45- 60	8.6	7.1	2.3	2.6	1.8	4.3
60- 75	5.3	3.3	2.6	2.2	2.8	3.4
75- 90	9.5	4.0	1.0	2.6	3.9	2.4
90-105	12.3	4.8	1.6	3.0	3.4	2.3
105-120	10.2	5.8	1.8	2.3	1.9	2.0
Average	14.2	8.5	6.6	4.8	7.7	7.4

TABLE 5-11. EXCHANGEABLE POTASSIUM ANALYSES OF SOILS FOR THE OLDFIELD WASTEWATER IRRIGATION STUDY (VALUES IN μg/g DRY SOIL)

	0 cm/week		5 cm/week		10 cm/week	
Depth (cm)	1975	1976	1975	1976	1975	1976
NO CUTTING MANAGEMENT						
0- 15	127.6	176.0	86.3	86.3	96.8	84.8
15- 30	77.0	95.5	46.3	63.8	42.8	62.3
30- 45	72.4	48.3	52.3	37.3	54.3	65.5
45- 60	50.0	47.8	50.5	55.0	47.8	52.8
60- 75	45.6	67.8	55.3	40.3	37.8	42.0
75- 90	49.6	65.0	54.0	34.5	40.8	56.3
90-105	48.2	53.7	53.0	34.0	33.5	88.7
105-120	60.8	53.7	44.5	48.3	30.8	29.8
Average	66.4	75.9	55.3	49.9	48.0	60.3
ONE CUTTING MANAGEMENT						
0- 15	177.5	206.5	146.0	164.3	131.6	116.6
15- 30	82.0	110.8	72.8	69.0	50.2	53.5
30- 45	96.8	98.5	49.3	53.0	46.4	67.0
45- 60	76.7	114.0	54.5	48.3	36.6	56.5
60- 75	49.2	73.8	42.7	44.4	33.5	35.3
75- 90	63.0	70.5	37.2	40.3	33.6	40.5
90-105	57.8	63.3	45.5	40.5	50.2	42.8
105-120	64.5	55.3	44.8	41.5	37.0	64.0
Average	83.4	99.1	61.6	62.6	52.4	59.5
TWO CUTTING MANAGEMENTS						
0- 15	302.0	192.6	97.5	68.3	91.5	97.0
15- 30	85.3	70.5	46.0	51.8	45.3	100.0
30- 45	66.0	61.5	31.8	60.0	38.5	69.0
45- 60	52.0	48.8	34.0	50.0	56.3	50.8
60- 75	54.0	45.5	41.0	59.7	48.3	48.8
75- 90	63.0	47.5	52.3	54.5	56.3	35.0
90-105	52.0	41.0	52.5	41.3	56.5	42.3
105-120	47.0	37.8	41.0	49.3	80.5	52.0
Average	90.2	68.1	49.5	54.3	59.1	61.8

TABLE 5-12. EXCHANGEABLE CALCIUM ANALYSES OF SOILS FOR THE OLDFIELD WASTEWATER IRRIGATION STUDY (VALUES IN μg/g DRY SOIL)

	0 cm/week		5 cm/week		10 cm/week	
Depth (cm)	1975	1976	1975	1976	1975	1976
			NO CUTTING MANAGEMENT			
0- 15	840.2	836.3	1107.0	1071.8	851.3	1034.8
15- 30	704.8	777.3	863.3	793.0	659.8	854.8
30- 45	800.2	652.0	1225.3	717.3	970.5	1267.0
45- 60	743.6	736.3	1470.0	1020.5	913.8	1152.3
60- 75	808.6	966.0	1660.3	1672.3	799.5	891.3
75- 90	1066.2	1530.0	2264.7	2291.3	1350.0	2020.8
90-105	1231.4	1367.7	2092.7	2983.0	2397.5	2061.7
105-120	1689.8	2003.7	2965.5	3087.8	2654.3	3972.3
Average	985.6	1108.6	1706.1	1704.6	1324.6	1656.8
			ONE CUTTING MANAGEMENT			
0- 15	763.3	798.2	1036.5	1354.2	1121.8	1346.5
15- 30	693.0	819.3	1036.0	1261.3	893.0	1785.3
30- 45	755.3	635.0	1383.8	1571.0	1399.0	1233.8
45- 60	720.7	1108.6	1191.8	1567.8	1274.8	1146.8
60- 75	581.6	856.8	1229.7	1481.4	814.3	910.3
75- 90	1020.0	1676.0	1057.0	1544.5	1805.2	1839.0
90-105	2419.5	2375.3	1925.5	1596.8	2641.6	2735.0
105-120	1556.3	2318.3	1624.8	1625.0	1892.2	2248.3
Average	1063.7	1323.4	1310.6	1500.2	1480.2	1655.6
			TWO CUTTING MANAGEMENTS			
0- 15	1138.0	874.0	621.0	879.6	821.0	1075.2
15- 30	890.7	875.3	560.0	678.3	753.3	864.3
30- 45	759.7	945.3	509.5	3491.3	649.3	1184.3
45- 60	775.0	993.8	638.0	747.8	1053.8	830.8
60- 75	780.3	1517.8	1025.0	1086.0	900.0	848.3
75- 90	880.0	2086.5	1974.3	1163.3	1127.5	1057.3
90-105	1412.7	2037.3	1870.5	1165.3	1572.8	1529.0
105-120	1688.3	2034.5	1988.0	2414.3	1909.5	1680.0
Average	1040.6	1420.5	1148.3	1453.2	1098.4	1133.6

TABLE 5-13. EXCHANGEABLE MAGNESIUM ANALYSES OF SOILS FOR THE OLDFIELD WASTEWATER IRRIGATION STUDY (VALUES IN μg/g DRY SOIL)

	0 cm/week		5 cm/week		10 cm/week	
Depth (cm)	1975	1976	1975	1976	1975	1976
NO CUTTING MANAGEMENT						
0- 15	134.6	99.6	172.0	155.7	158.0	168.8
15- 30	104.0	83.3	145.3	105.5	137.8	152.0
30- 45	138.6	80.5	203.7	103.3	220.0	241.0
45- 60	121.4	78.3	231.5	177.0	200.8	238.3
60- 75	146.0	162.3	289.0	200.0	181.5	208.3
75- 90	204.8	276.0	298.3	195.5	175.8	313.8
90-105	221.0	214.7	288.3	160.8	159.5	252.7
105-120	285.6	253.3	227.3	171.3	160.0	348.0
Average	169.5	156.0	231.9	158.6	174.2	240.3
ONE CUTTING MANAGEMENT						
0- 15	103.3	91.8	215.3	228.7	181.8	233.8
15- 30	102.0	83.5	148.0	195.8	115.2	195.3
30- 45	120.3	79.0	179.0	172.0	146.2	142.0
45- 60	95.3	199.4	189.8	242.8	132.0	151.0
60- 75	97.8	144.8	217.0	99.8	117.8	125.3
75- 90	235.8	254.5	155.4	117.8	116.8	97.8
90-105	266.8	338.5	182.3	127.3	142.0	136.8
105-120	317.8	294.0	168.3	143.0	130.0	149.8
Average	167.4	185.7	181.9	165.9	135.2	153.9
TWO CUTTING MANAGEMENTS						
0- 15	176.7	105.7	134.5	166.3	156.3	186.2
15- 30	126.3	96.0	69.5	124.5	96.5	148.3
30- 45	146.3	121.5	83.5	142.5	101.8	181.3
45- 60	134.3	159.5	124.0	139.5	162.3	137.3
60- 75	153.3	108.8	220.8	230.3	175.0	148.3
75- 90	190.3	84.3	297.0	255.8	249.8	121.3
90-105	233.3	126.0	329.0	289.8	262.0	171.5
105-120	176.0	136.0	214.5	262.0	319.5	189.8
Average	167.1	117.2	184.1	201.3	190.4	160.5

TABLE 5-14. EXCHANGEABLE SODIUM ANALYSES OF SOILS FOR THE OLDFIELD WASTEWATER IRRIGATION STUDY (VALUES IN μg/g DRY SOIL)

	0 cm/week		5 cm/week		10 cm/week	
Depth (cm)	1975	1976	1975	1976	1975	1976
			NO CUTTING MANAGEMENT			
0- 15	32.0	27.7	44.7	81.1	52.0	90.3
15- 30	33.0	28.0	72.7	92.8	69.8	109.0
30- 45	32.4	43.8	80.3	80.5	83.8	118.3
45- 60	33.8	29.3	88.5	115.5	55.3	95.0
60- 75	36.2	27.0	94.0	87.3	48.5	85.8
75- 90	45.0	36.5	67.7	69.8	56.5	107.3
90-105	44.0	38.3	52.3	66.3	54.0	96.7
105-120	48.4	43.0	56.8	62.3	66.5	81.0
Average	38.1	34.2	69.6	81.9	60.8	97.9
			ONE CUTTING MANAGEMENT			
0- 15	31.5	25.0	50.8	130.8	53.6	119.0
15- 30	32.3	28.5	65.3	131.3	63.6	120.0
30- 45	25.8	31.8	86.8	111.3	73.8	114.8
45- 60	26.3	28.0	74.5	114.0	55.4	101.0
60- 75	30.0	29.0	46.0	81.8	52.0	78.5
75- 90	39.0	33.0	50.2	73.8	51.4	88.8
90-105	53.3	35.5	51.8	64.0	47.6	78.5
105-120	47.5	41.7	50.3	62.8	54.2	89.3
Average	35.7	31.6	59.4	96.2	56.5	98.7
			TWO CUTTING MANAGEMENTS			
0- 15	30.3	26.8	40.8	99.0	44.3	94.9
15- 30	34.3	25.8	57.5	90.3	64.3	99.3
30- 45	28.0	31.3	54.0	79.3	57.3	89.3
45- 60	32.7	28.5	58.5	86.0	76.5	89.5
60- 75	34.0	32.5	61.3	149.3	67.5	92.0
75- 90	35.3	39.3	69.8	88.3	68.0	76.8
90-105	35.3	31.8	60.3	66.3	58.3	89.5
105-120	72.0	37.0	53.5	71.3	76.5	92.0
Average	37.8	31.6	56.9	91.2	64.1	90.4

TABLE 5-15. POTASSIUM SULFATE EXTRACTABLE CHLORIDE ANALYSES OF SOILS FOR THE OLDFIELD WASTEWATER IRRIGATION STUDY (VALUES IN μg/g DRY SOIL)

	0 cm/week		5 cm/week		10 cm/week	
Depth (cm)	1975	1976	1975	1976	1975	1976
			NO CUTTING MANAGEMENT			
0- 15	5.1	10.7	16.0	34.7	19.8	33.3
15- 30	10.4	8.4	13.1	29.7	13.3	32.1
30- 45	4.6	7.5	14.7	26.8	12.5	28.4
45- 60	4.6	7.2	11.9	35.5	10.6	27.0
60- 75	6.0	6.4	23.4	27.8	10.4	25.2
75- 90	7.9	9.1	20.4	28.6	13.7	33.7
90-105	8.0	7.3	20.3	29.6	21.1	36.2
105-120	6.8	8.8	25.3	35.2	24.6	28.4
Average	6.7	8.2	18.1	31.0	15.8	30.5
			ONE CUTTING MANAGEMENT			
0- 15	11.9	11.9	15.9	41.6	14.5	35.5
15- 30	6.6	7.7	9.5	31.6	10.7	31.4
30- 45	14.4	9.3	13.8	34.6	11.0	29.6
45- 60	7.7	7.8	12.9	34.1	11.6	27.2
60- 75	5.9	8.5	16.4	32.3	11.3	24.0
75- 90	6.1	7.5	11.9	29.2	14.1	28.7
90-105	8.7	9.1	17.2	26.7	18.3	26.8
105-120	6.9	10.3	14.6	23.5	14.6	27.4
Average	8.5	9.0	14.0	31.7	13.3	28.8
			TWO CUTTING MANAGEMENTS			
0- 15	11.0	10.5	20.0	39.8	15.8	30.6
15- 30	6.7	8.5	12.3	24.0	10.5	22.8
30- 45	3.8	7.3	9.4	25.2	10.0	21.7
45- 60	4.6	6.2	12.3	26.6	10.0	23.6
60- 75	5.0	8.8	16.4	27.5	14.6	21.1
75- 90	6.5	8.1	21.7	25.5	17.9	26.0
90-105	6.5	6.7	20.6	31.0	21.2	25.5
105-120	6.8	7.4	27.8	29.2	24.9	26.8
Average	6.4	7.9	17.6	28.6	15.6	24.8

TABLE 5-16. POTASSIUM SULFATE EXTRACTABLE NITRATE-NITROGEN ANALYSES OF SOILS FOR THE OLDFIELD WASTEWATER IRRIGATION STUDY (VALUES IN μg/g DRY SOIL)

	0 cm/week		5 cm/week		10 cm/week	
Depth (cm)	1975	1976	1975	1976	1975	1976
			NO CUTTING MANAGEMENT			
0- 15	4.5	1.5	1.8	2.2	19.6	2.5
15- 30	5.1	1.1	10.2	1.5	2.4	2.0
30- 45	1.1	0.9	5.8	1.1	2.1	1.7
45- 60	0.9	0.8	12.9	1.3	0.9	1.6
60- 75	1.0	0.6	6.2	1.1	1.2	1.5
75- 90	1.8	0.9	5.8	1.3	2.5	2.3
90-105	1.8	0.7	1.0	1.2	1.9	2.5
105-120	1.7	1.0	2.0	1.7	2.3	2.1
Average	2.2	0.9	5.7	1.4	4.1	2.0
			ONE CUTTING MANAGEMENT			
0- 15	5.8	1.8	11.7	3.6	17.6	4.0
15- 30	3.1	1.0	6.3	2.1	2.2	2.6
30- 45	2.4	1.0	2.9	1.9	3.6	2.2
45- 60	0.8	0.9	2.8	1.4	1.6	1.8
60- 75	1.6	1.0	1.4	1.2	1.5	1.8
75- 90	0.7	0.8	1.8	0.9	3.0	1.4
90-105	1.5	1.1	1.9	1.1	1.4	1.3
105-120	1.1	1.1	1.0	0.9	2.1	1.2
Average	2.1	1.1	3.7	1.6	4.1	2.0
			TWO CUTTING MANAGEMENTS			
0- 15	7.8	1.9	14.2	1.7	2.3	4.5
15- 30	4.2	1.4	2.1	1.1	1.6	3.0
30- 45	1.6	1.1	2.2	1.0	1.2	2.4
45- 60	4.2	0.7	1.9	1.1	1.1	2.2
60- 75	2.9	0.8	1.5	1.2	1.8	1.5
75- 90	1.7	0.9	1.3	1.1	1.7	2.0
90-105	1.3	0.8	1.2	1.3	2.0	1.8
105-120	2.3	0.8	16.1	1.4	1.8	2.0
Average	3.2	1.0	5.1	1.2	1.7	2.4

Runoff

Runoff from a tile drain that drains the 3.6 ha oldfield irrigation site plus 7.7 ha area of adjacent unirrigated oldfields was monitored using an ISCO sequential sampler in 1976 and 1977 (TABLES 5-17 to 5-21). Monitoring of the tile upstream of the spray irrigation site indicated that there was very little runoff from the 7.7 ha unirrigated area and that this runoff occurred only during Spring runoff or during one or two large rainfall events during other seasons. Thus, the majority of the runoff can be assigned to the 3.6 ha irrigation area. If the runoff is assigned to the entire 11.32 ha oldfield drainage area, the unit area loads resulting from wastewater irrigation are likely to be low (TABLES 5-17 to 5-21). If all the runoff were assigned to just the 3.6 ha spray irrigation area, the unit area loads estimate would be slightly high, especially during Spring runoff, but would be very close to actual runoff from this area. The average wastewater application over the area was 7.5 cm/week with half the area receiving 5 cm/week and the other half receiving 10 cm/week. If all runoff were assigned to the 3.6 ha spray irrigation area, maximum unit area load losses would be 2.96 kg/ha total P, 9.80 kg/ha NO_3-N, 0.43 kg/ha NH_4-N, 0.18 kg/ha NO_2-N, 7.78 kg/ha kjeldahl N, and 207.55 kg/ha chloride. The maximum mineral or inorganic N runoff losses would be 10.41 kg N/ha and the maximum organic N losses would be 7.35 kg N/ha. All of the mass balances for the spray irrigation plots (TABLES 5-5, 5-6, and 5-9) were calculated by assuming no runoff. The amount retained on site could be in error by as much as twice the above if all runoff originated from the 10 cm/week, 1.8 ha area (TABLES 5-6 and 5-9). In any event, such losses are only 6-7% of the total amount of each constituent applied in wastewater and would not change the retention figures in the mass balances to any significant degree. Thus, the mass balances are substantially correct as calculated in TABLES 5-4, 5-5, 5-6, and 5-9.

Even though only 7% or less of the constituents applied in wastewater ranoff, peak concentrations were still quite high and sometimes exceeded the 1.0 mg P/ℓ Michigan wastewater standard (Figure 5-7) and approached the 10 mg NO_3-N/ℓ EPA interim drinking water standard (Figure 5-8). The likely explanation for these high peak concentrations is that sand lenses

TABLE 5-17. STREAM EXPORT OF MOLYBDATE REACTIVE PHOSPHORUS AND TOTAL PHOSPHORUS FROM THE 11.32 ha OLDFIELD IRRIGATION SITE*

Season	EVENT FLOWS Rising Hydrograph (kg)	EVENT FLOWS Descending Hydrograph (kg)	Non-Event Flows (kg)	Export Total (kg)	% of Total	Unit Area Loads (kg/ha)
		MOLYBDATE	REACTIVE	PHOSPHORUS		
Summer, 1976	0.096 ± 0.001	0.719 ± 0.029	0.026 ± 0.014	0.841 ± 0.032	----	0.074
Fall, 1976	0	0	0	0	0	0
Winter, 1976-77	0	0	0	0	0	0
Spring Runoff 1977	0.191 ± 0.000	2.991 ± 0.069	0.004 ± 0.000	3.186 ± 0.069	----	0.281
Spring Post Runoff '77	ND**	ND	ND	ND	ND	ND
Summer, 1977	ND	ND	ND	ND	ND	ND
Total 76-77 Water Year	----	----	----	----	----	----
% of Total	----	----	----	----	----	----
		TOTAL	PHOSPHORUS			
Summer, 1976	0.111 ± 0.001	0.797 ± 0.027	0.035 ± 0.016	0.943 ± 0.031	----	0.083
Fall, 1976	0	0	0	0	0	0
Winter, 1976-77	0	0	0	0	0	0
Spring Runoff 1977	0.580 ± 0.000	7.261 ± 0.446	0.007 ± 0.000	7.848 ± 0.446	73.71	0.693
Spring Post Runoff '77	0.089 ± 0.001	0.191 ± 0.006	0.020 ± 0.000	0.300 ± 0.006	2.82	0.026
Summer, 1977	1.193 ± 0.019	1.268 ± 0.069	0.038 ± 0.000	2.499 ± 0.072	23.47	0.221
Total 76-77 Water Year	1.862 ± 0.019	8.720 ± 0.451	0.065 ± 0.000	10.647 ± 0.451		0.940
% of Total	17.49	81.90	0.61			

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[*] The unit area loads were calculated for the 11.32 ha total area drained; the irrigation area was only 3.6 ha; the average irrigation rate was 7.5 cm/week for the entire site.

[**] ND indicates no data.

TABLE 5-18. STREAM EXPORT OF NITRATE AND AMMONIA NITROGEN FROM THE 11.32 ha OLDFIELD IRRIGATION SITE*

Season	EVENT FLOWS					
	Rising Hydrograph (kg)	Descending Hydrograph (kg)	Non-Event Flows (kg)	Export Total (kg)	% of Total	Unit Area Loads (kg/ha)
			NITRATE-NITROGEN			
Summer, 1976	0.385 ± 0.003	1.785 ± 0.026	0.260 ± 0.034	2.430 ± 0.043	----	0.215
Fall, 1976	0	0	0	0	0	0
Winter, 1976-77	0	0	0	0	0	0
Spring Runoff 1977	7.815 ± 0.000	16.973 ± 0.273	0.051 ± 0.000	24.839 ± 0.273	70.38	2.194
Spring Post Runoff '77	0.916 ± 0.004	1.285 ± 0.014	0.003 ± 0.000	2.204 ± 0.015	6.25	0.195
Summer, 1977	3.107 ± 0.030	4.953 ± 0.128	0.188 ± 0.000	8.248 ± 0.131	23.37	0.728
Total 76-77 Water Year	11.838 ± 0.030	23.211 ± 0.302	0.242 ± 0.000	35.291 ± 0.303		3.118
% of Total	33.54	65.77	0.69			
			AMMONIA-NITROGEN			
Summer, 1976	0.010 ± 0.0001	0.090 ± .002	0.016 ± 0.004	0.116 ± .005	----	
Fall, 1976	0	0	0	0	0	0
Winter, 1976-77	0	0	0	0	0	0
Spring Runoff 1977	0.046 ± 0.000	0.528 ± .008	0.002 ± 0.000	0.576 ± .008	37.31	0.051
Spring Post Runoff '77	0.040 ± 0.001	0.030 ± .0004	0.001 ± 0.00001	0.071 ± .001	4.60	0.006
Summer, 1977	0.825 ± 0.001	0.069 ± .001	0.003 ± 0.000	0.897 ± .001	58.10	0.079
Total 76-77 Water Year	0.911 ± 0.001	0.627 ± .008	0.006 ± 0.00001	1.544 ± .008		0.136
% of Total	59.00	40.61	0.39			

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* The unit area loads were calculated for the 11.32 ha total area drained; the irrigation area was only 3.6 ha; the average irrigation rate was 7.5 cm/week for the entire site.

TABLE 5-19. STREAM EXPORT OF NITRITE AND KJELDAHL NITROGEN FROM THE 11.32 ha OLDFIELD IRRIGATION SITE*

Season	--------- EVENT FLOWS --------					
	Rising Hydrograph (kg)	Descending Hydrograph (kg)	Non-Event Flows (kg)	Total Exports (kg)	% of Total	Unit Area Loads (kg/ha)
			NITRITE-NITROGEN			
Summer, 1976	0.071 ± 0.001	0.349 ± .016	0.024 ± 0.026	0.444 ± .031	----	0.039
Fall, 1976	0	0	0	0	0	0
Winter 1976-77	0	0	0	0	0	0
Spring Runoff 1977	0.057 ± 0.000	0.383 ± .007	0.0007 ± 0.000	0.441 ± .007	67.33	0.039
Spring Post Runoff '77	0.006 ± 0.0001	0.017 ± .001	0.0002 ± 0.000	0.023 ± .001	3.51	0.002
Summer, 1977	0.098 ± 0.001	0.092 ± .003	0.001 ± 0.000	0.191 ± .004	29.16	0.017
Total 76-77 Water Year	0.161 ± 0.001	0.492 ± .008	0.002 ± 0.000	0.655 ± .008		0.058
% of Total	24.58	75.11	0.31	100.00		
			KJELDAHL-NITROGEN			
Summer, 1976	0.335 ± 0.002	1.568 ± .028	0.183 ± 0.035	2.086 ± .045	----	0.184
Fall, 1976	0	0	0	0	0	0
Winter, 1976-77	0	0	0	0	0	0
Spring Runoff 1977	3.241 ± 0.000	17.681 ± .463	0.038 ± 0.000	20.960 ± .463	74.82	1.852
Spring Post Runoff '77	0.447 ± 0.001	1.584 ± .031	0.010 ± 0.000	2.041 ± .031	7.29	0.180
Summer, 1977	2.094 ± 0.017	2.792 ± .092	0.126 ± 0.000	5.012 ± .094	17.89	0.443
Total 76-77 Water year	5.782 ± 0.017	22.057 ± .473	0.174 ± 0.000	28.013 ± .474		2.475
% of Total	20.64	78.74	0.62			

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* The Unit Area Loads were calculated for the 11.32 ha total area drained; the irrigation area was only 3.6 ha; the average irrigation rate was 7.5 cm/week.

TABLE 5-20. STREAM EXPORT OF CHLORIDE AND SUSPENDED SOLIDS FROM THE 11.32 ha OLDFIELD IRRIGATION SITE*

Season	--------- EVENT FLOWS --------- Rising Hydrograph (kg)	Descending Hydrograph (kg)	Non-Event Flows (kg)	Total Exports (kg)	% Total	Unit Area Load (kg/ha)
			C H L O R I D E			
Summer, 1976	37.90 ± 0.26	153.68 ± 0.10	22.33 ± 0.21	213.91 ± 0.35	----	18.90
Fall, 1976	0	0	0	0	0	0
Winter 1976-77	0	0	0	0	0	0
Spring Runoff 1977	151.22 ± 0.00	311.06 ± 2.34	1.29 ± 0.00	463.57 ± 2.34	62.04	40.95
Spring Post Runoff '77	16.19 ± 0.19	57.01 ± 0.22	0.77 ± 0.00	73.97 ± 0.29	9.90	6.53
Summer, 1977	96.89 ± 0.73	106.43 ± 0.12	6.31 ± 0.00	209.63 ± 0.74	28.06	18.52
Total 76-77 Water Year	264.30 ± 0.75	474.50 ± 2.35	8.37 ± 0.00	747.17 ± 2.47		66.00
% of Total	35.37	63.51	1.12			
			S U S P E N D E D S O L I D S			
Summer, 1976	2.96 ± 0.02	20.89 ± 1.48	1.91 ± 1.03	25.76 ± 1.80	----	2.28
Fall, 1976	0	0	0	0	0	0
Winter, 1976-77	0	0	0	0	0	0
Spring Runoff 1977	ND**	477.30 ± 35.46	ND	ND	ND	ND
Spring Post Runoff '77	ND	ND	ND	ND	ND	ND
Summer, 1977	ND	ND	ND	ND	ND	ND
Total 76-77 Water Year	---	---	---	---	----	---
% of Total	---	---	---	---	----	---

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* The Unit Area Loads were calculated for the 11.32 ha total area drained; the irrigation area was only 3.6 ha; the average irrigation rate was 7.5 cm/week.

** ND indicates no data.

TABLE 5-21. STREAM EXPORT OF SODIUM AND CALCIUM FROM THE 11.32 ha OLDFIELD IRRIGATION SITE*

Season	-------- EVENT FLOWS -------- Rising Hydrograph (kg)	Descending Hydrograph (kg)	Non-Event Flows (kg)	Total Exports (kg)	% of Total#	Unit Area Load (kg/ha)
			SODIUM			
Summer, 1976	32.89 ± 0.17	99.98 ± 1.42	13.26 ± 0.79	146.13 ± 1.63	----	12.91
Fall, 1976	0	0	0	0	0	0
Winter, 1976-77	0	0	0	0	0	0
Spring Runoff 1977	135.01 ± 0.00	259.50 ± 18.92	0.29 ± 0.00	394.80 ± 18.92	----	34.88
			CALCIUM			
Summer, 1976	48.28 ± 0.36	91.60 ± 0.10	16.22 ± 0.89	156.10 ± 0.97	----	13.79
Fall, 1976	0	0	0	0	0	0
Winter, 1976-77	0	0	0	0	0	0
Spring Runoff 1977	371.29 ± 0.00	314.48 ± 0.81	2.70 ± 0.00	688.47 ± 0.81	----	60.82

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* The Unit Area Loads were calculated for the 11.32 ha total area drained; the irrigation area was only 3.6 ha; the average irrigation rate was 7.5 cm/week.

No complete water year data available.

and eroded areas allowed direct connection to the tile drain during the actual spray irrigation. Some eroded areas resulting in cave-ins and direct holes leading to the tile were found and filled in but others could have been missed. Similar problems for tile drainage from a wastewater irrigation study of corn at a nearby area have been reported and attributed to direct connection to the tiles via sand lenses.[24] It would appear that oldfield areas with good infiltration characteristics should not be tiled and that an effort to control runoff would increase the renovation efficiency of such sites by utilizing the renovation potential of the soil-plant system to the greatest extent.

It is also interesting to note that 99% or more of every constituent measured in runoff was exported during runoff events with low flow contributing less than 1% to the total amount exported. The importance of runoff events in losses is likely the result of the high peak concentrations of each constituent as discussed above (Figures 5-7 and 5-8), the low concentrations in low flow, and the fact that almost all discharge during the summer and fall is wastewater generated with the tile drain drying up between each wastewater application.

CONCLUSIONS AND RECOMMENDATIONS

The oldfield proved to be very effective in the treatment of municipal wastewater. Nitrate concentrations in the water leaching past the 120 cm depth stayed within recommended drinking water quality limits throughout the irrigation season. Phosphorus concentrations in soil-water remained at background levels during the study period.

While the unharvested vegetation effectively prevented nitrate movement with recharge waters, harvest of the vegetation provided assurance that N would be removed from the site and therefore could not build up to leach out at some later time. The harvest also lengthened the effective life of the soil for retention of P by removing a substantial portion of the added P.

Tile drains for such oldfield systems should be avoided if possible since peak concentrations of N and P sometimes exceeded drinking water and/or wastewater standards. High peak concentrations represented only a

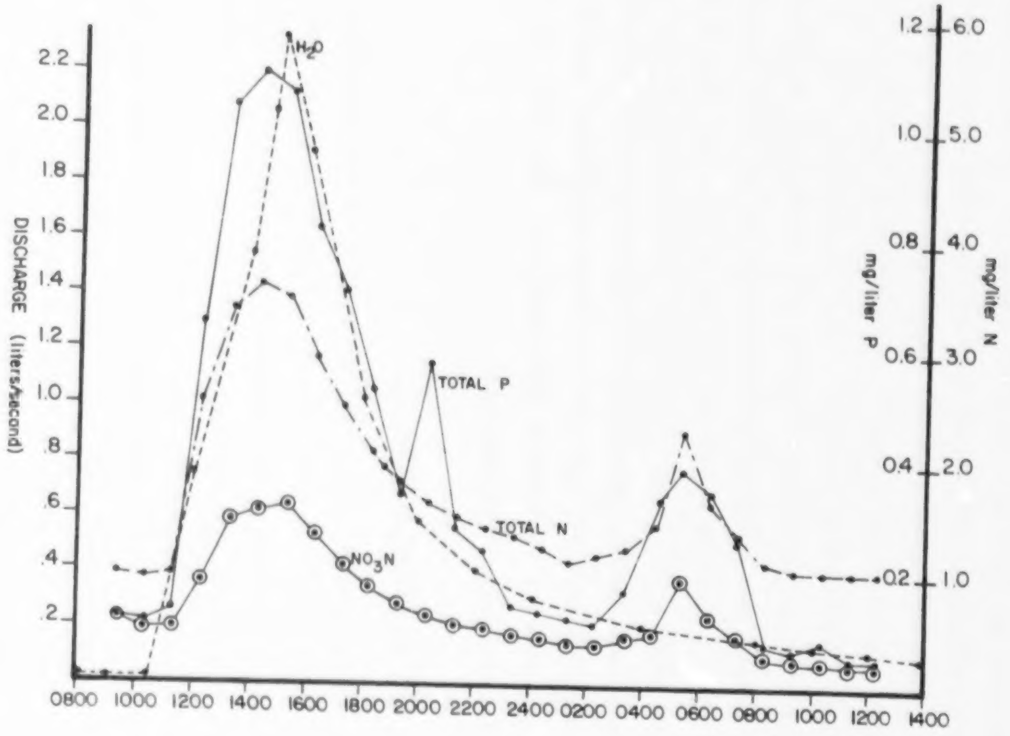

Figure 5-7. Concentration versus discharge for total P, total N, and NO_3-N for a wastewater irrigation generated runoff event (August 16, 1976).

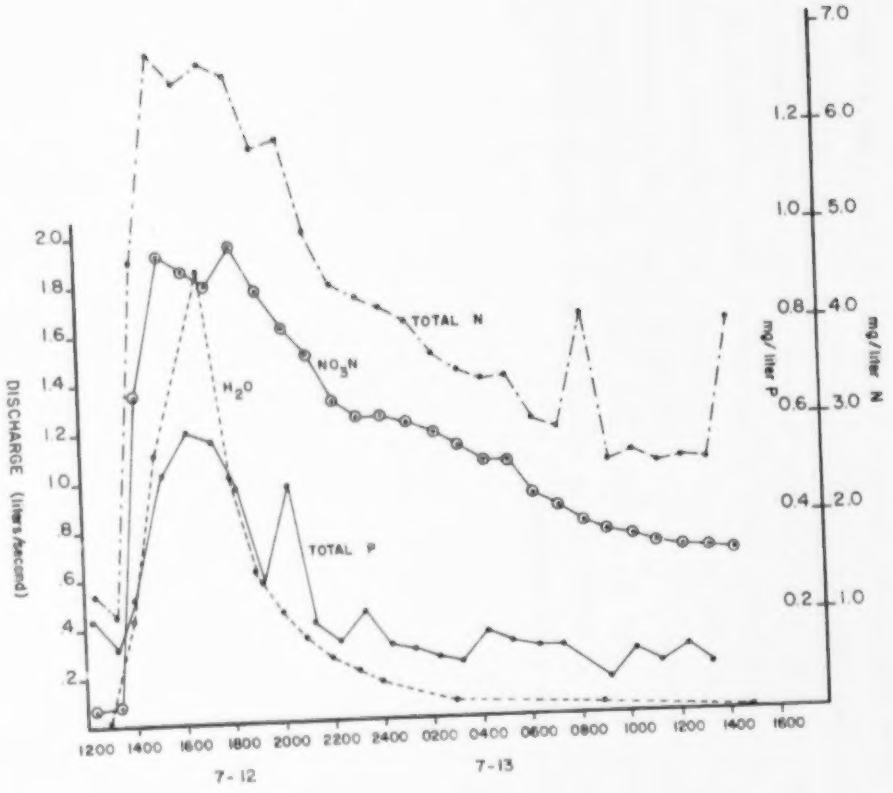

Figure 5-8. Concentration versus discharge for total P, total N, and NO_3-N for a wastewater irrigation generated runoff event (July 12, 1976).

small fraction of total applied wastewater but could still lead to local eutrophication problems if not controlled.

Use of oldfields for wastewater treatment has the advantage that productive agricultural lands do not need to be purchased or leased for the treatment of wastewater. Consideration should be given to use of harvest material for green manure, compost or animal feed when the oldfields are harvested.

The grass cutting management demonstrated that simpler management schemes are available which will effectively prevent nitrate leaching. Because the life of the land application system could be lengthened by harvest, this management would be preferable where maximum design life is desired. However, when harvest of the grass is unfeasible, frequent mowing can effectively control nitrate leaching at least for short duration systems. Without harvest or cutting, the grass was still effective, but the vegetation would probably revert to an oldfield flora if the no cutting management option were adopted.

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SECTION 6

LAND APPLICATION TO CROPLANDS

James E. Hook and M.B. Tesar

INTRODUCTION

In implementing Public Law 92-500, municipal planners must evaluate land treatment as an alternative for conventional wastewater treatment. To make a proper evaluation, planners must be able to design a land treatment system which has a predictable performance. When considering a conventional treatment plant, designers have a choice of components -- each component having a generally predictable performance for a given range of conditions. However, when considering land treatment, designers have few choices with known effectiveness for the one, perhaps most critical component, the vegetation. To aid them in planning and designing, we need to recommend crops which will have predictable effectiveness for renovation of wastewater, particularly with respect to nitrogen. We need to offer alternatives in crops and in management which improve effectiveness while minimizing operational problems.

Wastewater treatment systems which use rates of water much in excess of crop needs are common. These systems do not necessarily behave as conventionally fertilized and irrigated cropland, particularly with respect to nitrogen nutrition and leaching. Field studies evaluating performance of several crops irrigated with municipal effluent have been or are being conducted at several locations.[1-8] With most, at least one of the objectives has been to develop crop or other vegetation management systems which will effectively remove nitrogen from the wastewater thereby preventing groundwater or surface water contamination.

A study to assess the effectiveness of a variety of forage crop species and managements for removal of nitrogen and other major nutrients from wastewater was initiated as part of the IJC studies as an adjunct to crop response studies already underway on the Water Quality Management Facility (WQMF) at Michigan State University. The purpose of this study was to compare the effectiveness of several important agronomic crops in the land treatment of municipal wastewaters. More specifically, it sought to determine how growth and harvest of the crops affects when and how much of wastewater constituents may leach to and contaminate groundwater. Furthermore, this leachate quality should serve as an indication of runoff quality from such land application areas where runoff occurs.

MATERIALS AND METHODS

Site Description

The experimental site was located in the northwest corner of the Water Quality Management Facility (WQMF) wastewater irrigation site on the campus of the Michigan State University. The soil was classified by high intensity mapping as a Miami loam. This soil is a member of the fine-loamy, mixed mesic family of Typic Hapludalfs developed on silt to loam till. Chemical analyses of major horizons are provided in TABLE 6-1. The soil was naturally well drained, but tensiometer measurements made during the middle of the summer irrigation season just prior to one of the irrigation

TABLE 6-1. MEAN CONCENTRATIONS OF BRAY EXTRACTABLE P, EXCHANGEABLE CATIONS AND pH OF ALL TREATMENT PLOTS AT THE START OF THE 1976 to 1977 STUDY PERIOD (VALUES IN μg/g DRY SOIL)

Depth (cm)	Bray P	K	Ca	Mg	Na	pH
15	12.5	43	1406	88	94	7.6
30	4.0	36	903	86	93	7.3
60	2.9	51	993	154	91	6.7
90	3.0	55	1295	255	94	6.8
120	2.1	47	2083	261	90	7.5
150	1.0	40	2779	220	88	7.9
180	0.8	35	2902	181	83	8.2
210	1.0	36	2810	177	80	8.2
240	1.6	31	2513	149	82	8.2
270	1.4	30	2246	138	84	8.2
300	1.2	24	1824	100	78	8.4

periods indicated the formation of a perched water table in the range of the 1.0 to 1.8 m depth under the high irrigation treatment. This perched water table did not subside completely between the three weekly applications.

Plot Design and Treatments

A split plot design was used to compare effects of weekly irrigation levels, crop types and species or varieties. The split of crop type into species or varieties was not of direct concern for this study. The weekly irrigation rates were 2.5, 5.0 and 7.5 cm/week. The crop types were perennial grasses, perennial legumes, annuals and no vegetation. Each plot containing the crop type was 9.1 x 18.2 m and was replicated three times within each irrigation rate. Because of physical limitations irrigation rates were not replicated.

The perennial grasses and legumes were established in August 1973. The grasses were *Phalaris arundinacea*, L., *Festuca arundinacea*, Schreb., *Dactylis glomerata*, L., *Alopecurus arundinacea*, Poir, *Poa pratensis*, Leyss, *Phleum pratense*, Leyss, and two varieties of *Bromus inermis*, Leyss. The legume plots contained two varieties of *Lotus corniculatus*, L. and six of *Medicago sativa*, L. The annuals, two varieties of *Zea mays*, L., *Sorghum sudanense*, P. Stapf, and *Sorghum bicolor*, L. Moench, were planted no-till into a fall sown crop of rye which had been killed by herbicide treatment with "Roundup" just prior to planting. The no vegetation plots were sprayed with "Roundup" as needed to eliminate all plant growth. A small amount of fertilizer was used on all cropped plots. The annuals received 22.4, 9.7, 111.5 kg/ha of N, P, and K, respectively, in a band 50 mm to the side and 50 mm below the row at planting. The grasses and legumes received the same amounts as the annuals by broadcast application following either the first or second harvest each year.

Municipal sewage effluent was taken from a pipeline from the East Lansing Sewage Treatment Plant. This water was of poor tertiary quality in 1974 and 1975 and was of secondary quality during the 1976-77 study period reported here. During periods of peak pumping, water was back-siphoned from the first of four effluent receiving lakes; this back-siphoning generally lowered the total N concentrations of effluent sprayed onto the site because of N stripping processes occuring in the lake. All effluent was chlorinated just prior to spraying.

Effluent was applied at a rate of 3.81 cm/hour in 1974 and 1975 and at 0.85 cm/hour in 1976 and 1977 for the time period necessary for a daily application of 2.5 cm. The three weekly rates of 2.5, 5.0 and 7.5 cm were accomplished by irrigating 1, 2 and 3 days per week, respectively. The irrigation season was usually from mid-spring to mid-fall.

Sampling and Analyses

Wastewater was sampled from each application with acid washed polyethylene funnel collectors placed one meter above the ground. Soil-water was sampled using porous cup vacuum type samplers evacuated to 0.8 atmospheres immediately before one weekly irrigation and sampled 48 hours later. The porous cups were placed at depths of 15 and 150 cm below the surface and were connected by small diameter acrylic tubing to a sample vacuum chamber located on the surface about [illegible] m from the cup location. This separation of cup and sample chamber eliminated traffic in the vegetation around the sampler, prevented short circuiting of effluent from ground surface to the cups and facilitated harvest.

Though the crop plots contained more than one species or variety, the sampling devices were placed in the same species in each replicate. Thus, samplers in the annual plots were always in the center of one of the 3.0 x 9.1 m corn sub-plots; in the legume plots, they were always in the alfalfa sub-plot; and in the grass plots, they were always in either the reed canary grass sub-plot, the tall fescue sub-plot, or in the orchard grass sub-plot. These three species had similar yields. These sub-plots were too small to be certain that mixing of leachate from neighboring plots did not affect soil-water at the 150 cm depth, but were large enough to be certain that annual plots were not affected by grass plots, etc.

Rainfall was monitored with a weighing rain gauge located 0.3 km from the plots. Wastewater application was calculated from pumping records and measured discharge rates of sprinklers on the site. No runoff was observed at the sampled plots when irrigated at the hourly rates used in 1976 and

1977. Evapotranspiration and groundwater recharge were calculated by the mass balance approach of Thornthwaite and Mather.[9]

Effluent was analyzed for NO_3-N, NH_4-N, organic N, total P, pH, Cl, Na, K, Ca, and Mg. Soil-water was analyzed weekly for NO_3-N, NH_4-N, ortho-P, and Cl in 1976 and was analyzed on monthly composites for organic N, Ca, Mg, Na, and K. All analyses followed standard techniques or modifications described in Section 5.

RESULTS AND DISCUSSION

The effectiveness of crop plants in preventing nutrient escape from effluent irrigated farms depends upon their ability to take up and immobilize those nutrients until harvest permanently removes them. The monthly applications of major plant nutrients (TABLE 6-2) of the effluent and

TABLE 6-2. MONTHLY AND YEARLY APPLICATIONS OF CROP NUTRIENTS AND SALTS ON THE 7.5 cm/WEEK IRRIGATION RATE * (VALUES IN kg/ha UNLESS OTHERWISE STATED)

Month	Effluent (cm)	N**	P	K	Ca	Mg	Na
Apr 76	5.8	6.10	1.27	5.59			
May 76	23.5	51.93	14.57	132.50			
June 76	37.8	73.17	11.43	49.39			
July 76	35.0	44.42	5.28	35.22			
Aug 76	32.5	40.64	10.43	32.16			
Sep 76	32.5	60.17	10.55	34.90			
Oct 76	10.0	17.95	3.82	10.83			
TOTAL	177.1	294.38	57.35	300.59	1363	450	1566
Apr 77	0.0	--	--	--			
May 77	24.7	49.20	16.15	142.09			
June 77	36.3	34.86	9.14	38.05			
July 77	35.4	49.31	9.72	34.55			
Aug 77	35.3	37.88	8.98	32.77			
Sep 77	25.1	25.64	6.13	25.40			
Oct 77	22.8	33.77	8.36	23.60			
TOTAL	179.6	230.65	58.48	296.46	1034	454	1765

* Applications to the 2.5 and 5.0 cm/week treatments would be approximately one-third and two-thirds of these amounts, respectively.

** Excludes precipitation input.

fertilizer was fairly uniform, except for K where fertilization added 100 kg/ha at one time. The uniform application of plant nutrients provided by the effluent was well suited to the growth of and uptake by the perennial grasses and legumes which were harvested three times per growing season. However, the monthly application of effluent during May and June provided considerably more of the nutrients than could be taken up by the annuals in those months. The P and K in excess of uptake needs could be expected to be retained by the soil. The excess nitrogen, however, would likely be mineralized and nitrified and thus subject to leaching.

The concentration of mineral N in the soil-water (Figures 6-1 to 6-6) verified the leaching which occurred with the annuals. Following the planting of the corn and other annuals on week 21 of 1976 and week 18 of 1977, mineral N, almost entirely NO_3-N, sharply increased in the root zone of the annuals (Figures 6-1 to 6-3). Nearly simultaneously, increases occurred 150 cm below surface of the 5.0 and 7.5 cm/week applications (Figures 6-5 and 6-6). At the 2.5 cm/week irrigation rate only a gradual increase in mineral N concentration occurred at 150 cm (Figure 6-4). When irrigated at 2.5 cm/week the net recharge during May and June averaged 16.8 cm, while it averaged 39.2 and 56.3 cm for the 5.0 and 7.5 cm/week rates, respectively. The low recharge prevented leaching of the excess mineral N from the topsoil to the groundwater. The inability of the annuals to use the excess N applied in these early growth months and the inability of the soil to retain nitrate against the leaching pressure of the higher application rates resulted in recharge of water containing nitrate in excess of 10 mg/ℓ.

Once the annuals began to take up the N, mineral N in soil-water in the root zone (Figures 6-1 to 6-3) and subsequently at the 150 cm depth (Figures 6-4 to 6-6) diminished rapidly. The annuals were as effective as perennial grasses during this time in preventing N leaching. In fact, growth of corn on the 2.5 and 5.0 cm/week plots was limited by availability of N. At those irrigation rates, yields of the corn were 15 to 55% lower than at the 7.5 cm/week rate. Any N lost by leaching or denitrification would further widen the deficiency. Any decrease in yields due to N deficiency would be expected to lower the uptake of P and other nutrients as well.

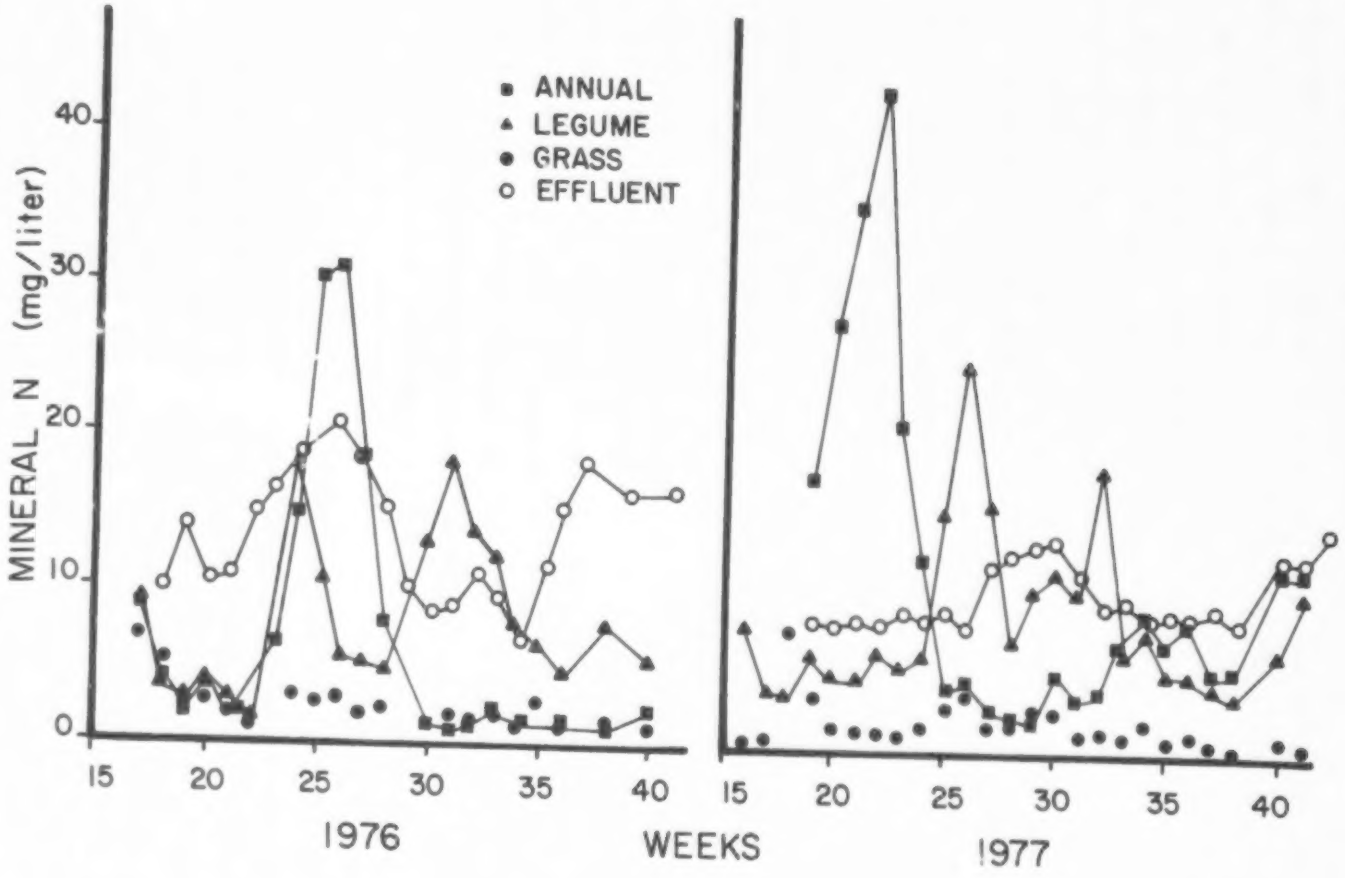

Figure 6-1: Weekly average mineral N concentrations in applied effluent and in soil-water from the 15 cm depth of the 2.5 cm/week irrigation rate of the various crop types.

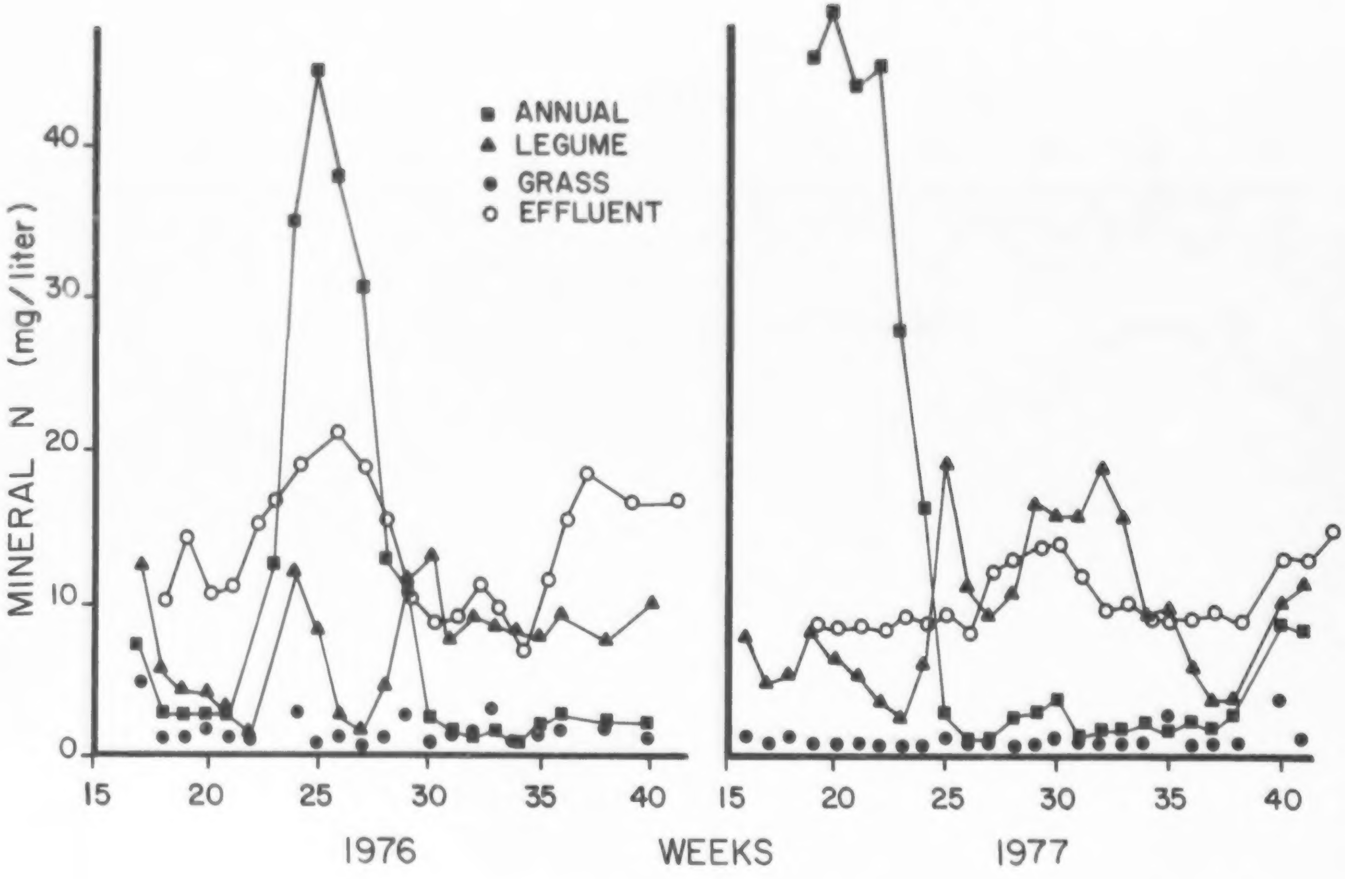

Figure 6-2: Weekly average mineral N concentrations in applied effluent and in soil-water from the 15 cm depth of the 5.0 cm/week irrigation rate of the various crop types.

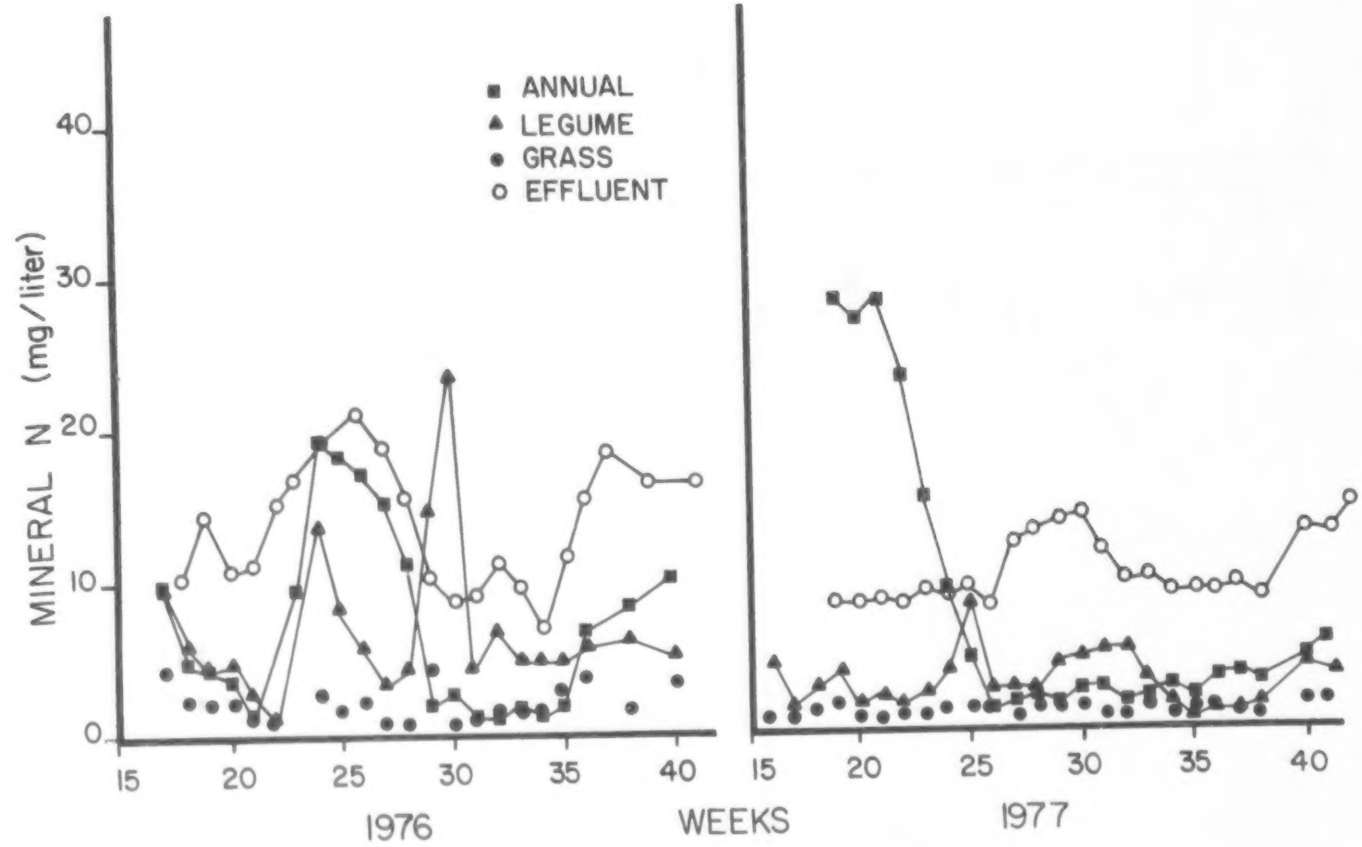

Figure 6-3: Weekly average mineral N concentrations in applied effluent and in soil-water from the 15 cm depth of the 7.5 cm/week irrigation rate of the various crop types.

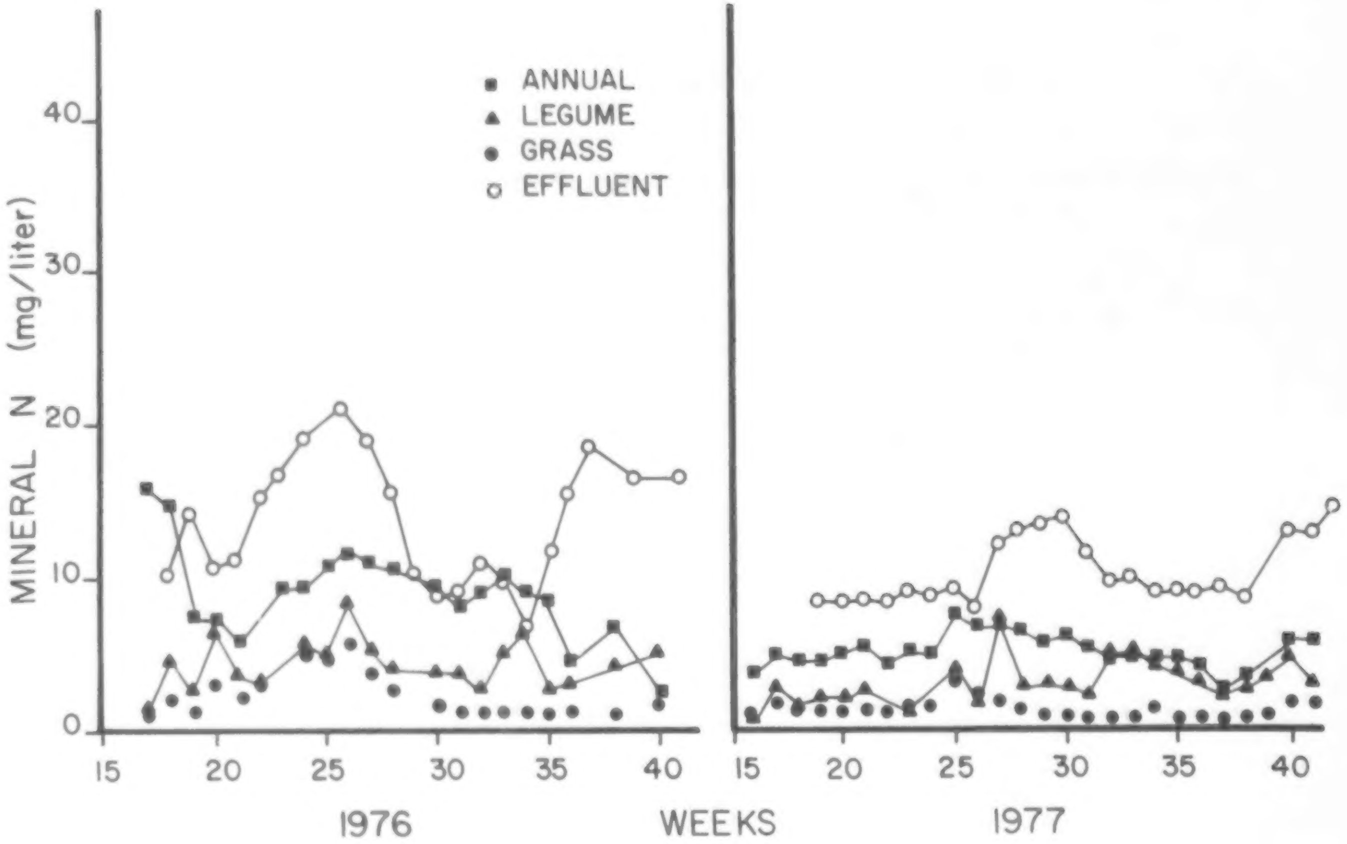

Figure 6-4: Weekly average mineral N concentrations in applied effluent and in soil-water from the 150 cm depth of the 2.5 cm/week irrigation rate of the various crop types.

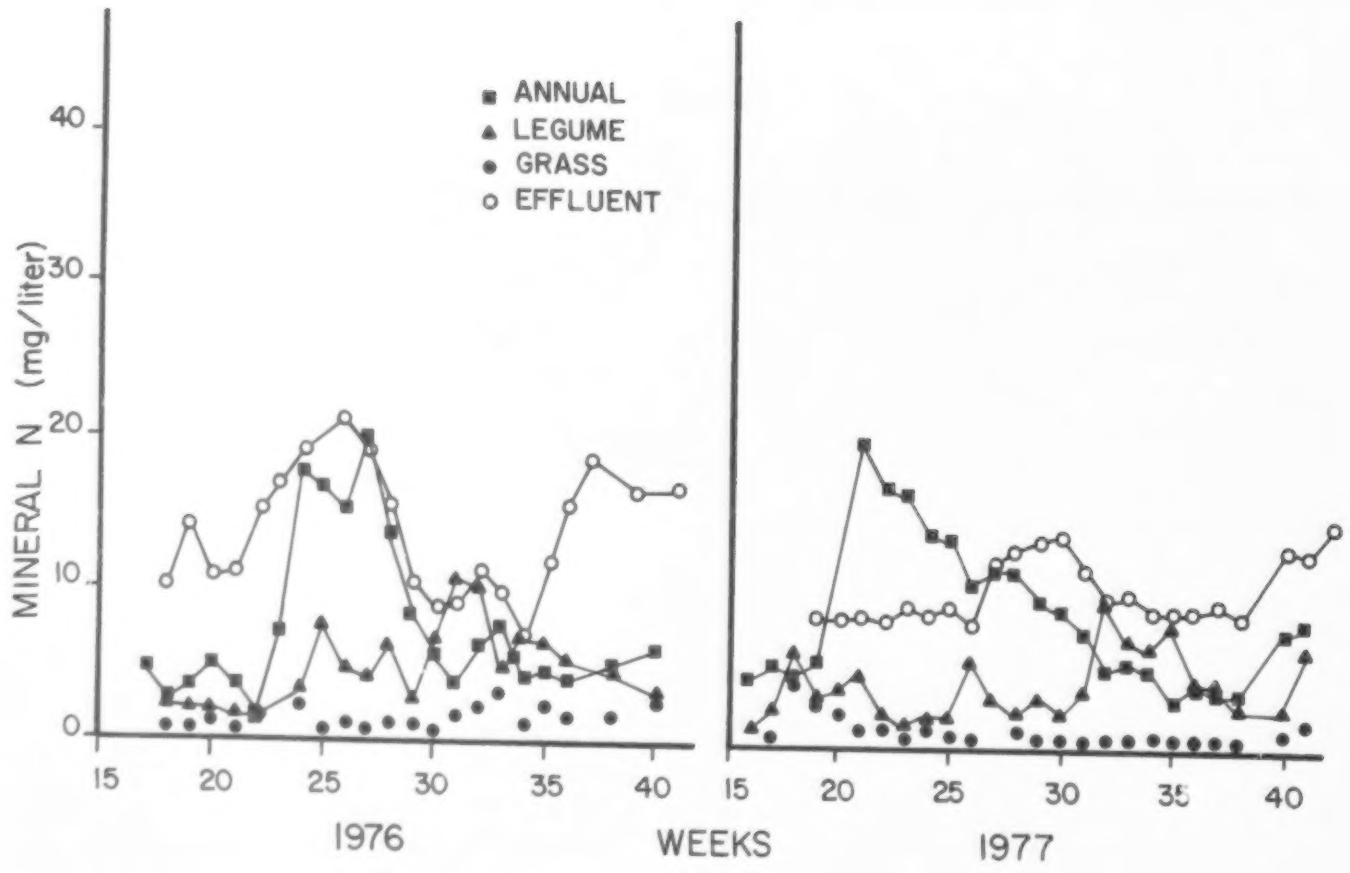

Figure 6-5: Weekly average mineral N concentrations in applied effluent and in soil-water from the 150 cm depth of the 5.0 cm/week irrigation rate of the various crop types.

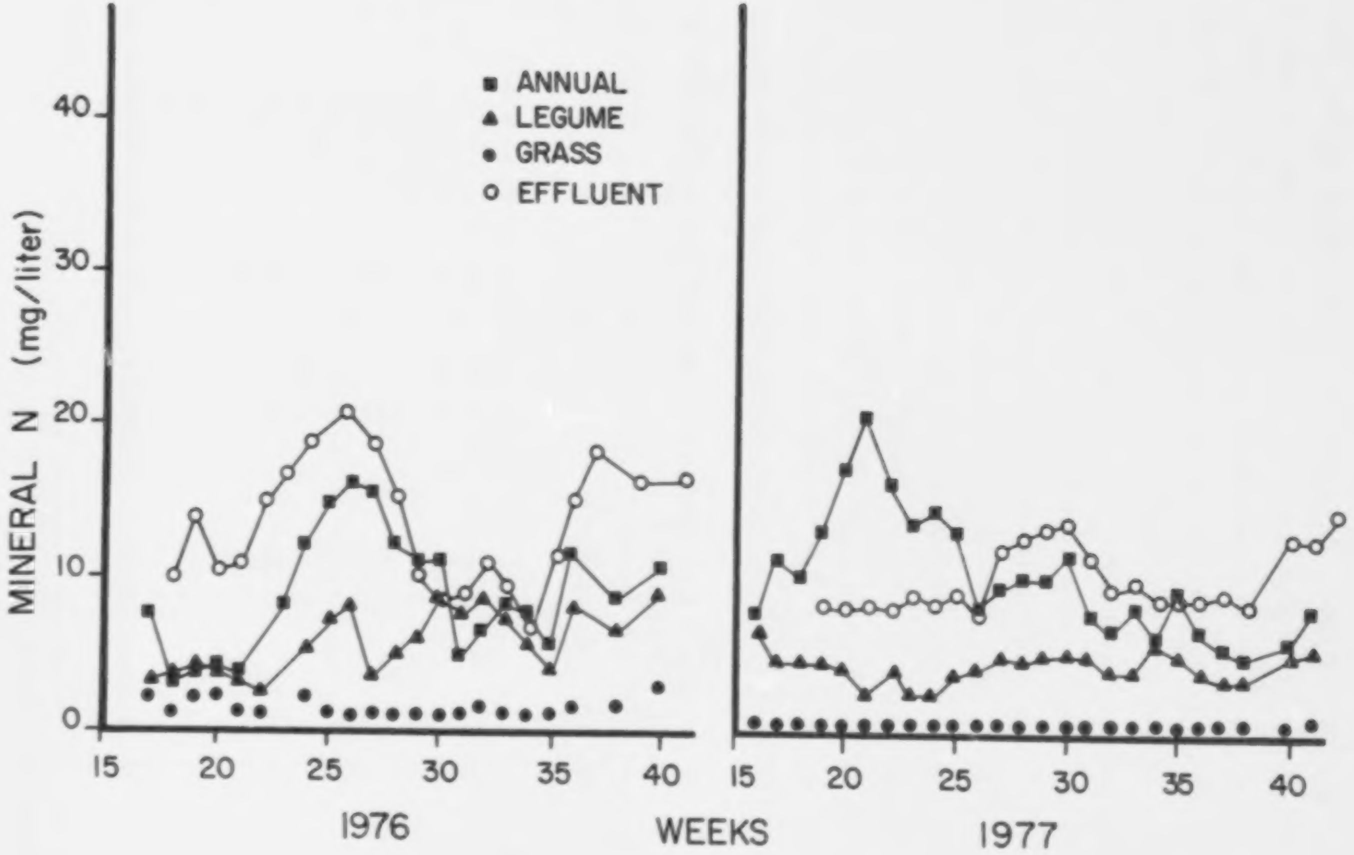

Figure 6-6: Weekly average mineral N concentrations in applied effluent and in soil-water from the 150 cm depth of the 7.5 cm/week irrigation rate of the various crop types.

The mass balance for mineral N for the 1976-1977 water year (TABLE 6-3 to 6-5) pointed out the comparative effectiveness of the crop types within each irrigation rate. At all three rates, the perennial grasses effectively controlled N leaching. At the highest irrigation rate (TABLE 6-5) the 207 kg/ha of total N applied was less than the 377 kg N/ha reported in harvest of reed canary grass in effluent irrigated pastures.[3] Growth and yields of the perennial grasses which included reed canary grass, therefore, may have been limited by the availability of N especially at the 2.5 and 5.0 cm/week irrigation rates. The 1976 and 1977 average yields of the three grass species, in which the soil-water samples were located, increased from 5.82 metric tons/ha at 2.5 cm/week to 8.80 and 10.73 metric tons/ha at the 5.0 and 7.5 cm/week levels, respectively. Because the perennial grasses effectively removed mineral N, total annual losses were less than 10 kg N/ha under all three irrigation rates (TABLES 6-3 to 6-5) and mineral N concentrations in the leachate never exceeded 5 mg N/ℓ (Figures 6-4 to 6-6).

TABLE 6-3. MASS BALANCE FOR INORGANIC N FOR THE 2.5 cm/WEEK CROP SITE (VALUES IN kg/ha)

Month	Precipitation Input	Irrigation* Input	Total Input	Grass Recharge	Legume Recharge	Annuals Recharge
Oct 76	1.52	5.56	7.08	0.68	2.40	1.07
Nov 76	0.59	0.00	0.59	0.26	0.87	0.50
Dec 76	0.38	0.00	0.38	0.17	0.49	0.38
Jan 77	0.28	0.00	0.28	0.12	0.31	0.31
Feb 77	4.65	0.00	4.65	0.18	0.43	0.56
Mar 77	2.05	0.00	2.05	0.53	1.08	1.96
Apr 77	3.00	0.00	3.00	0.50	0.83	2.18
May 77	0.36	29.55	29.91	0.00	0.00	0.00
June 77	3.01	11.71	14.72	2.44	3.05	7.74
July 77	1.29	13.95	15.24	0.02	0.06	0.10
Aug 77	1.77	12.40	14.17	0.37	2.60	3.21
Sep 77	3.35	6.77	10.12	0.70	2.90	3.97
ANNUAL	22.25	79.94	102.19	5.97	15.02	21.98
% Input	28.00	78.00	100.00	6.00	15.00	22.00

* "Irrigation" input includes 22.4 kg N/ha added in fertilizer.

TABLE 6-4. MASS BALANCE FOR INORGANIC N FOR THE 5.0 cm/WEEK CROP SITE (VALUES IN kg/ha)

Month	Precipitation Input	Irrigation Input*	Total Input	No Vegetation Recharge	Grass Recharge	Legume Recharge	Annuals Recharge
Oct 76	1.52	8.23	9.75	8.53	1.75	3.19	4.35
Nov 76	0.59	0.00	0.59	2.54	0.43	0.58	1.15
Dec 76	0.38	0.00	0.38	1.76	0.24	0.34	0.70
Jan 77	0.28	0.00	0.28	1.41	0.15	0.23	0.52
Feb 77	4.65	0.00	4.65	2.49	0.20	0.34	0.80
Mar 77	2.05	0.00	2.05	8.62	0.50	0.97	2.43
Apr 77	3.00	0.00	3.00	9.27	0.36	0.86	2.37
May 77	0.36	35.77	36.13	13.70	1.28	2.55	8.68
June 77	3.01	21.80	24.81	63.78	1.99	6.61	36.65
July 77	1.29	28.87	30.16	28.57	0.59	3.05	13.00
Aug 77	1.77	24.77	26.54	56.43	0.74	13.65	10.22
Sep 77	3.35	13.30	16.65	37.04	1.12	6.24	7.94
ANNUAL	22.25	132.74	154.99	234.14	9.35	38.61	88.81
% Input	17.00	86.00	100.00	177.00**	6.00	25.00	57.00

* "Irrigation" input includes 22.4 kg N/ha added in fertilizer.

** Total Input for the no vegetation plots was only 132.59 kg N/ha since they were not fertilized.

TABLE 6-5. MASS BALANCE FOR INORGANIC N FOR THE 7.5 cm/WEEK CROP SITE (VALUES IN kg N/ha)

Month	Precipitation Input	Irrigation Input*	Total Input	No Vegetation Recharge	Grass Recharge	Legume Recharge	Annuals Recharge
Oct 76	1.52	12.34	13.86	10.55	3.15	8.87	10.55
Nov 76	0.59	0.00	0.59	2.08	0.55	1.70	2.19
Dec 76	0.38	0.00	0.38	1.27	0.28	1.00	1.32
Jan 77	0.28	0.00	0.28	0.90	0.17	0.69	0.96
Feb 77	4.65	0.00	4.65	1.42	0.20	1.04	1.55
Mar 77	2.05	0.00	2.05	4.38	0.38	3.04	4.90
Apr 77	3.00	0.00	3.00	4.21	0.13	2.75	4.84
May 77	0.36	42.39	42.75	16.16	0.49	5.40	25.36
June 77	3.01	32.65	35.66	50.03	0.18	12.75	50.08
July 77	1.29	42.27	43.56	21.08	0.42	10.59	23.06
Aug 77	1.77	36.15	37.92	35.22	0.77	14.64	23.76
Sep 77	3.35	19.72	23.07	45.91	0.74	9.86	14.41
ANNUAL	22.25	185.52	207.77	193.21	7.46	72.33	162.98
% Input	12.00	89.00	100.00	104.00**	4.00	35.00	78.00

* "Irrigation" input includes 22.4 kg N/ha added in fertilizer.

** Total Input for the no vegetation plots was only 185.37 kg N/ha since they were not fertilized.

With the perennial legumes, nitrate in the root zone increased to concentrations greater than 10 mg/ℓ immediately following each harvest (Figures 6-1 to 6-3). The effect was short lived. As the plants recovered they again removed much of the added N and, overall, were effective in preventing excess nitrate leaching at all three irrigation rates (Figures 6-4 to 6-6 and TABLES 6-3 to 6-5). Because the legumes could fix N to make up any deficiency caused by low applications, yields were not affected by N levels. Rather the higher irrigation rates increased disease problems and lowered yields. The 1976-1977 average annual yields were 13.69, 12.10 and 10.17 metric tons/ha for the 2.5, 5.0 and 7.5 cm/week irrigation rates, respectively.

Mass balances (TABLE 6-3 to 6-5) point out that the annuals were much less effective over the year in preventing N from escaping the treatment site and that the effectiveness decreases with increasing irrigation rates. With no vegetation (TABLE 6-4 and 6-5), the amounts of N which leached past the 150 cm depth actually exceeded the amounts applied during the 1976-1977 water year. This treatment demonstrates the importance of the vegetation in preventing N from moving with recharge water.

Organic N and orthophosphate concentrations were (TABLES 6-6 and 6-7) measured during 1976 in soil-water samples. Organic N plus ammonium N concentrations decreased slightly with depth. There was no significant differences among either irrigation rates or crop type. Orthophosphate concentrations were low in both topsoil and subsoil. At the 15 cm depth average P concentrations were slightly higher in annual and no vegetation treatments and levels were near background levels observed in these soils. In this third year of effluent and fertilizer application, the soil-plant system is still effectively removing added P.

Soluble cations (TABLE 6-8) were also measured on monthly composites of soil-water samples in 1976. They indicate that sodium had largely equilibrated with the soil. The concentrations of Na in solution were nearly as high as in the effluent. Potassium was being depleted by plants, particularly the legumes in spite of the addition of 100 kg K/ha in the fertilizer.

TABLE 6-6. MEAN ANNUAL ORGANIC PLUS AMMONIUM NITROGEN CONCENTRATION IN THE SOIL-WATER SAMPLES TAKEN FROM THE TOPSOIL AND FROM BELOW THE ROOT ZONE OF THE CROPLAND IRRIGATION AREA, 1976 (VALUES IN mg N/ℓ ± ONE STD. DEV.)

TREATMENT			
Irrigation Rate (cm/week)	Vegetation	15 cm Depth	150 cm Depth
2.5	Annuals	2.28 ± 0.67	1.29 ± 1.11
	Legumes	2.15 ± 0.90	1.15 ± 0.43
	Grass	1.73 ± 0.63	0.84 ± 0.41
5.0	Annuals	1.63 ± 0.42	0.84 ± 0.35
	Legumes	2.00 ± 0.78	1.06 ± 0.71
	Grass	1.30 ± 0.19	0.76 ± 0.17
	No Crop	1.07 ± 0.35	0.32 ± 0.24
7.5	Annuals	1.54 ± 0.51	0.66 ± 0.60
	Legumes	1.99 ± 0.61	0.94 ± 0.82
	Grass	1.48 ± 0.45	0.66 ± 0.38
	No Crop	1.54 ± 0.73	0.89 ± 0.25

TABLE 6-7. MEAN ANNUAL ORTHOPHOSPHATE CONCENTRATION IN THE SOIL-WATER SAMPLES TAKEN FROM THE TOPSOIL AND FROM BELOW THE ROOT ZONE, 1976 (VALUES IN mg P/ℓ ± ONE STD. DEV.)

TREATMENT			
Irrigation Rate (cm/week)	Vegetation	15 cm Depth	150 cm Depth
2.5	Annuals	.074 ± .083	.042 ± .062
	Legumes	.019 ± .014	.025 ± .019
	Grass	.040 ± .050	.039 ± .040
5.0	Annuals	.091 ± .103	.082 ± .084
	Legumes	.032 ± .076	.024 ± .035
	Grass	.028 ± .037	.041 ± .069
	No Crop	.128 ± .142	.034 ± .046
7.5	Annuals	.106 ± .093	.023 ± .034
	Legumes	.053 ± .063	.026 ± .031
	Grass	.067 ± .095	.018 ± .027
	No Crop	.218 ± .160	.106 ± .079

TABLE 6-8. MEAN ANNUAL CONCENTRATION OF CATIONS IN THE EFFLUENT AND IN THE SOIL-WATER SAMPLES TAKEN FROM THE TOPSOIL AND FROM BELOW THE ROOT ZONE OF THE CROPLAND IRRIGATION AREAS, 1976 (VALUES IN mg/ℓ)

Irrigation Rate (cm/week)	Vegetation	K		Ca		Mg		Na	
		15 cm Depth	150 cm Depth	15 cm Depth	150 cm Depth	15 cm Depth	150 cm Depth	15 cm Depth	150 cm Depth
2.5	Annuals	11.7	2.0	81.5	57.4	14.6	29.6	64.4	31.1
	Legumes	2.7	0.7	64.9	78.7	10.2	38.9	79.5	44.0
	Grass	5.5	3.5	79.3	45.3	10.7	18.1	67.0	46.1
5.0	Annuals	11.7	5.3	78.1	56.4	14.9	18.7	99.8	72.1
	Legumes	2.7	0.7	62.2	53.5	10.7	22.6	88.4	65.6
	Grass	8.9	1.4	50.7	68.2	12.0	24.5	87.2	61.9
	No Crop	7.3	2.0	24.2	35.7	5.5	12.0	98.1	51.5
7.5	Annuals	7.4	3.4	41.9	42.1	10.3	18.5	87.3	73.2
	Legumes	3.8	1.9	53.0	43.8	14.6	16.0	100.0	79.7
	Grass	8.2	0.8	46.0	34.2	11.9	17.6	86.1	70.9
	No Crop	14.3	6.5	28.5	13.9	8.0	15.4	112.3	91.1
EFFLUENT		10.4		79.7		25.8		88.8	

CONCLUSIONS AND RECOMMENDATIONS

Nitrogen concentrations in soil-water of both the root zone and the subsoil varied widely during the growing season. The type of crop and the irrigation rate were related to the variation. The tall growing cool season grasses commonly used in pastures and grass hay of the Great Lakes Region effectively maintained N concentrations well below the 10 mg/ℓ limit for NO_3-N in drinking water. Discharges of N into the groundwater during the May through October irrigation season were less than 10 kg N/ha even at the 7.5 cm/week irrigation rate. Legumes were somewhat less effective than grasses in preventing discharge of N. Peak discharges occurred briefly following each harvest. The summer annuals contributed the greatest yearly N losses -- from 22 kg N/ha for the 2.5 cm/week rate to 163 kg N/ha for the 7.5 cm/week rates. At the 5.0 and 7.5 cm/week rates, most of the yearly discharge of N occurred during the first seven weeks following planting.

The results of this study demonstrate the need to adjust application of total wastewater and fertilizer closely to both the crop uptake characteristics and to the ability of crops to withstand excessive irrigation. For example, the grasses in this study were limited in growth by lack of N suggesting that irrigation could be started earlier, continued later, and possibly increased beyond 7.5 cm/week for part of the year to maximize application while maintaining a high degree of treatment. Increasing wastewater additions to most of the legume varieties proved to be detrimental to yields and decreased the effectiveness of land treatment. While most legumes would benefit from low weekly applications of wastewater, higher irrigation rates would require use of disease resistant varieties. Higher rates could be used if stands were maintained in a crop rotation scheme for only two or perhaps three years. Management of wastewater applications to annuals is more difficult because of their very short period of uptake. To prevent excessive N leaching, N should be eliminated from starter fertilizer and the weekly irrigation rate should be kept low so that evapotranspiration prevents recharge of much of the added wastewater until uptake increases. As uptake increases (after about 5-7 weeks), the irrigation rate should be increased to provide sufficient nutrients for weekly growth of the annuals.

Several crops have been demonstrated as suitable for use in land treatment for municipal wastewater; however, protection of groundwater and surface water aquifers requires that these cropland systems be managed intensively. Perennial grasses offer the most efficient N and P uptake and removal with least management. The added economic benefits to be derived from the legumes and annuals could make them attractive alternatives even with the much more intensive management required if they are used.

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SECTION 7

APPLICATION OF MUNICIPAL WASTEWATER TO FOREST LANDS

Thomas M. Burton and James E. Hook

INTRODUCTION

While the application of municipal wastewater on forests has been the object of numerous studies,[1-26] only very few of these studies have used a mass balance approach. Even so, the evidence to date would suggest that mature forests may not be the ideal place to recycle wastewater unless the application rate is low, usually 2.5 cm per week or less. Higher application rates often result in losses of nitrate-nitrogen to the groundwater at concentrations greater than the 10 mg/ℓ U.S.E.P.A. interim drinking water standard.[5] Since most studies have not used the mass balance approach, it is difficult to ascertain whether dilution by precipitation during winter months will result in yearly average concentrations below 10 mg N/ℓ or not. Thus, the feasibility of using forests for application of municipal wastewater remains an open question. There are also some data that suggest that during the initial operation of such forested land application systems mineralization and leaching of the large quantities of organic nitrogen from the litter and humus can result in nitrate-nitrogen contamination of groundwater.[5,14] This question also needs to be studied in more detail.

A mass balance study of nitrogen and phosphorus leaching from a wastewater application site was initiated in a late successional beech-sugar maple forest in southern Michigan in 1976 in order to provide better data on the feasibility of such application.

MATERIALS AND METHODS

Three 1.2 ha plots were established in a late successional forest dominated by sugar maple and beech (75 and 11% dominance, respectively, of $\geq$10 cm trunk diameter with 423 trees/ha and a mean basal area of 42 m^2/ha).[27] More detailed vegetation descriptions are available from Knobloch and Bird's area A[27] and from Frye.[28,29] One of these plots served as a non-irrigated control, another received 5 cm/week of chlorinated, secondary municipal wastewater from East Lansing, Michigan, and a third received 10 cm/week wastewater.

The soils underlying the sites were described by high intensity mapping.[30] The control and 5 cm/week plots are predominantly Miami-Marlette and Kalamazoo loams. These are well drained soils formed on glacial till materials. The Kalamazoo contains more sands and gravels than the Miami-Marlette. The 10 cm/week plot is principally Owosso sandy loam with some Brookston and Conover loams. The Owosso is well to moderately well drained and is developed in sandy loam overlying a loam to clay loam soil at 45 to 105 cm depth. The Brookston and Conover loams are poorly drained.

Wastewater was applied twice weekly to the forest floor at the rate of 8.4 mm/hr with Buckner 8600 agricultural spray nozzles from May 4 through October 13, 1976, and from April 19 through October 28, 1977.

Wastewater was sampled from each application with acid-washed polyethylene funnel collectors placed one meter above the forest floor. Porous cup vacuum-type tube lysimeters were installed at 10 sites in each plot at 15, 30, 60, 90, 120 and 150 cm depths and sampled weekly during the irrigation period by evacuating to 0.8 atmospheres and sampling 48 hours later for most sites or by evacuating a week in advance on a few of the drier sites on the 5 cm/week wastewater area and on all the control sites. The lysimeters were also sampled as often as possible throughout the winter.

Runoff from the site was sampled with ISCO sequential samplers on an event basis; these event samples were supplemented by several grab samples each week. Runoff from an adjacent upstream field into the woods was also monitored and runoff from the site during spring runoff and a few large storms was corrected for inputs from this source. Discharge into and from the site was calculated from stage-discharge relationships and monitored by Stevens Type F recorders and V-notch weirs.

Rainfall on the site was monitored with recording rain gauges located in adjacent oldfields. Wastewater application was calculated from pumping records and monitored in the field with wedge-shaped plastic "Tru-check" rain gauges. Evapotranspiration and recharge were calculated using Thornthwaite and Mather's technique.[31]

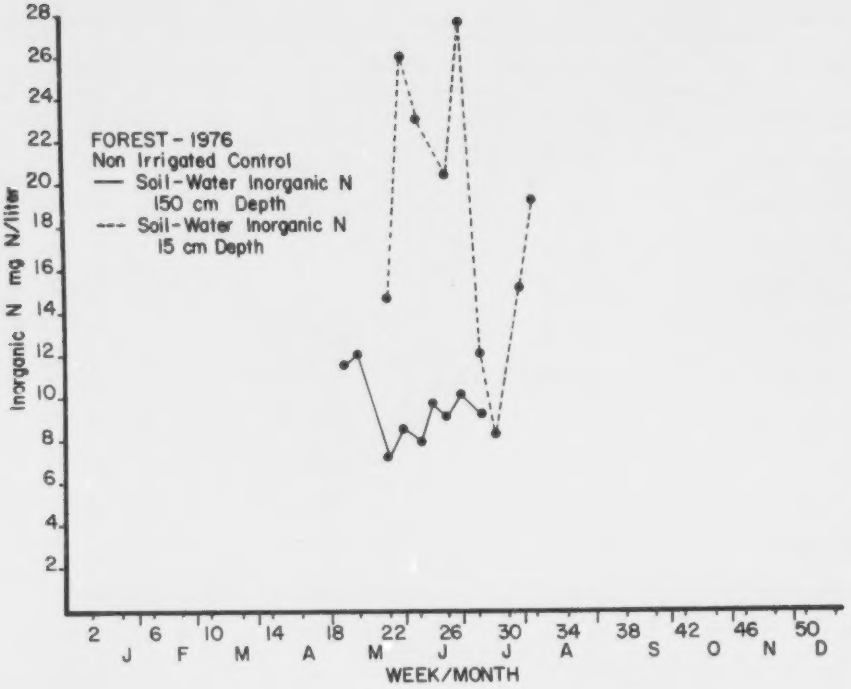
Soil-water and runoff samples were analyzed for NO_3-N, NO_2-N, NH_4-N, organic-N, total P, and chloride in both years. Molybdate reactive P, Ca, Mg, Na, and K were analyzed in 1976 on at least a monthly basis. Effluent samples were analyzed for all parameters in 1976 and 1977. All N and P analyses were done with standard autoanalyzer techniques[32] in 1977. In 1976, NO_3-N, NH_4-N, and Cl were analyzed with ion-selective electrodes; Cl was analyzed by electrode in 1977. Cations and heavy metals were analyzed using atomic adsorption spectrophotometry.

Soil samples were taken before irrigation in 1976 and after irrigation ceased in 1976 and 1977. The pre- and post-irrigation 1976 samples were analyzed for Bray extractable P, NO_3-N, NH_4-N (post-irrigation only), Cl, Ca, Mg, Na, and K using standard soil analysis techniques[33] or modifications as described in the methods section of Section 5.

RESULTS AND DISCUSSION

Nitrogen

The emphasis in this study was on nitrogen since many of the already cited studies[1-26] indicated that nitrate leaching was the major obstacle in utilization of forests for wastewater application. An unexpected finding was that inorganic concentrations were very high in soil-water in the non-irrigated control (Figure 7-1) compared to most reported literature values for either soil-water or stream water draining undisturbed forests.[34-39] This phenomenon may have been the result of lower than average rainfall resulting in very little water being available for runoff or recharge (TABLE 7-1). High concentrations of NO_3-N in soil-water in arid or semiarid regions due to lack of leaching and to capillary rise from the subsoil are well documented.[40] Thus, nitrate can be expected to build up during drought years and be "flushed out" in wet years in areas like Michigan where evapotransportation in an average year is only slightly less than



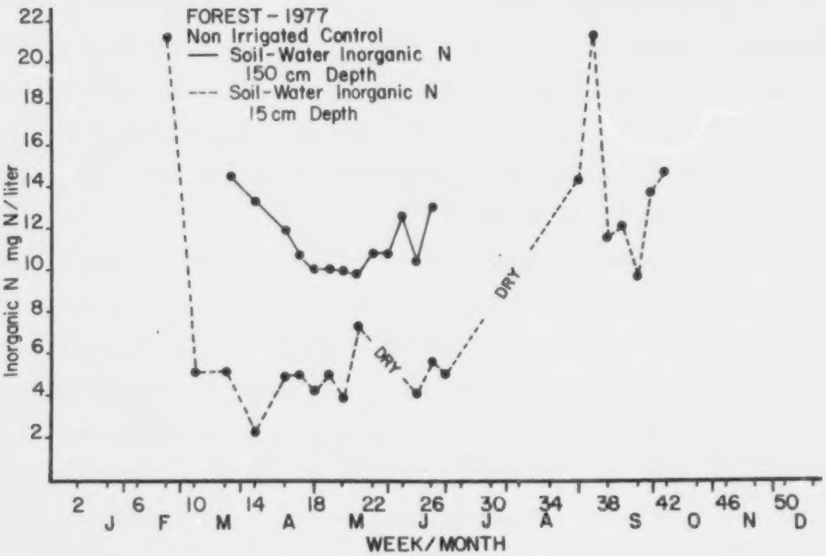


Figure 7-1: Inorganic N concentrations in soil-water at the 150 cm depth for the non-irrigated forest area.

TABLE 7-1. WATER BUDGET FOR NON-IRRIGATED FOREST (VALUES IN m^3/ha)

Month	Precipitation	Evapotranspiration	Runoff	Recharge
October 1976	520.7	285.0	0	0
November 1976	201.9	0	0	0
December 1976	129.5	0	0	0
January 1977	96.5	0	0	0
February 1977	159.2	0	0	0
March 1977	701.0	184.5	0	0
April 1977	1027.9	504.0	52.4	50.5
May 1977	124.5	994.5	0	0
June 1977	1030.4	1060.4	0	0
July 1977	442.0	1152.0	0	0
August 1977	607.1	917.1	0	0
September 1977	1148.1	811.2	0	0
TOTALS	6188.8	5908.6	52.4	50.5
% of Input	100	95.47	0.85	0.82

precipitation. Winter precipitation can be very important in this respect since the buildup of snow usually results in saturated soil conditions with some recharge during the spring. Thus, areas with similar amounts of annual precipitation but much greater snowfall than the 130 cm typical of the study area, would not be expected to show buildup of NO_3-N. Low NO_3-N concentrations in soil-water have previously been reported for northern lower Michigan and Minnesota forests.[35,37]

The consequences of the NO_3-N accumulation are of major importance to quality of groundwater recharge since at least the first flush of soil-water to groundwater could exceed the 10 mg N/ℓ drinking water standard.

A further consequence of the high inorganic N concentrations in the soil-water from the non-irrigated control plots is that comparisons on a concentration basis of wastewater irrigated plots to non-irrigated controls or to pre-irrigated soil-water values are not meaningful since pre-irrigated soil-water concentrations of NO_3-N were as high as wastewater values. Thus, comparisons must be made on a mass balance basis. On this basis, over 99% of input inorganic nitrogen was retained on the non-irrigated site in the 1976-77 water year. The only recharge or runoff occurred during April (TABLE 7-1) with only 0.17 kg N/ha of the 22.25 kg N/ha input from precipitation leaching from the site.

The mass balances for inorganic N for 1976-77 for 5 and 10 cm/week of wastewater irrigation (TABLES 7-2 and 7-3) show marked differences between the two sites. The 5 cm/week site retained very little of the added inorganic N (TABLE 7-2) and most leached past the 150 cm depth. This groundwater leaching was equivalent to 85% of the 190 kg/ha input. This figure assumes no runoff from this site. This assumption is based on on-site observations and chloride data. After spray began in May, 1976, it took until late September before soil-water chloride values at the 150 cm depth approached equilibrium with input chloride concentrations corrected for evapotranspiration (Figure 7-2). Using the chloride dilution to calculate the size of the soil-water storage pool for both the 5 and 10 cm/week areas strongly suggested that almost all runoff originated from the 10 cm/week plot and that all water from the 5 cm/week area percolated to groundwater. The chloride concentration increases with depth and time for the two sites were almost identical (Figure 7-2). This suggests that about the same amount of water percolated to depth for both sites. Therefore, the infiltration rate for the forest would appear to be about 5 cm/week with excess water running off the site. Thus, the 15% retention (renovation) of inorganic N by the 5 cm/week site (TABLE 7-2) appears accurate. This figure is very close to the 17% retention reported for a nine year study in Pennsylvania.[5]

Concentrations of inorganic N for the 5 cm/week site also indicate that little removal had taken place (Figure 7-3). Interpretation of this figure has to include the fact that chloride values did not approach input concentrations until September, 1976. Thus, wastewater input on this site was diluted by the existing soil-water pool until that time. Even so, concentrations at the 150 cm (output) depth were similar to input concentrations (Figure 7-3) in 1976. These concentrations were probably a result of the original high inorganic N concentrations (Figure 7-1) and increased mineralization and leaching of the native organic N pool. It is noteworthy that dilution by the existing soil-water pool extends over such a long

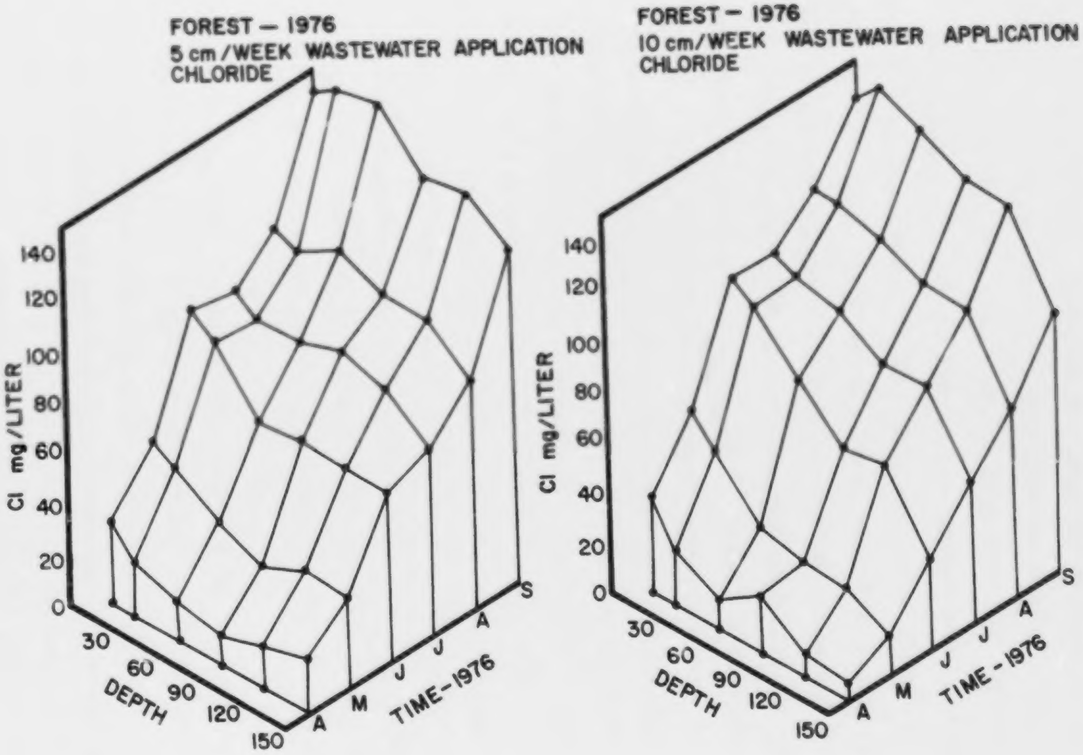


Figure 7-2: Chloride concentrations as a function of depth and time for the Forest Irrigation Site.

TABLE 7-2. MASS BALANCE FOR INORGANIC NITROGEN ($NO_3 + NO_2 + NH_4$-N) FOR THE 5 CM/WEEK FOREST IRRIGATION SITE (VALUES IN KG/HA)

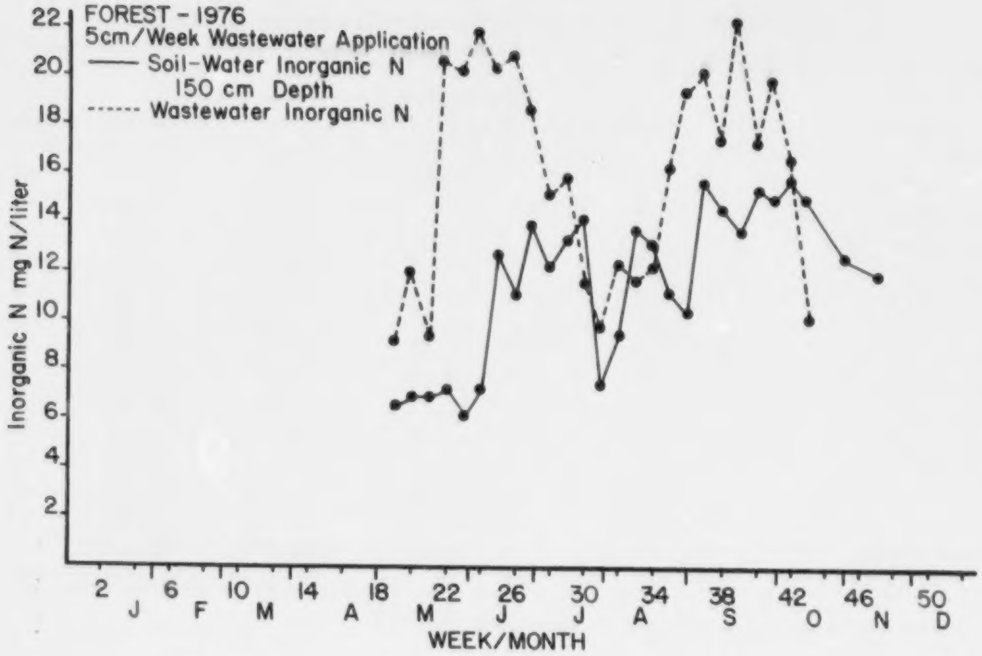
Month	Precipitation*	Wastewater Irrigation	Total Input	Recharge	Retention
October 1976	1.52	26.80	28.32	29.94	-1.62
November 1976	0.59	0	0.59	2.45	-1.86
December 1976	0.38	0	0.38	1.55	-1.17
January 1977	0.28	0	0.28	1.12	-0.84
February 1977	4.65	0	4.65	1.85	2.80
March 1977	2.05	0	2.05	5.22	-3.17
April 1977	3.00	11.28	14.28	19.58	-5.30
May 1977	0.36	18.79	19.15	10.93	8.22
June 1977	3.01	21.70	24.71	18.40	6.31
July 1977	1.29	33.20	34.49	15.12	19.37
August 1977	1.77	30.47	32.24	21.49	10.75
September 1977	3.35	25.19	28.54	34.19	-5.65
ANNUAL	22.25	167.43	189.68	161.84	27.84
% of Input	11.73	88.27	100.00	85.32	14.68

* Based on mean literature values for Michigan.

TABLE 7-3. MASS BALANCE FOR INORGANIC NITROGEN ($NO_3 + NO_2 + NH_4$-N) FOR THE 10 CM/WEEK FOREST IRRIGATION SITE (VALUES IN KG/HA)

Month	Precipitation*	Wastewater Irrigation	Total Input	Runoff	Recharge	Retention
October 1976	1.52	47.43	48.95	10.65	4.19	34.11
November 1976	0.59	0	0.59	1.97	0	-1.38
December 1976	0.38	0	0.38	0	0.42	-0.04
January 1977	0.28	0	0.28	0	0.26	0.02
February 1977	4.65	0	4.65	0	0.35	4.30
March 1977	2.05	0	2.05	1.94	0	0.11
April 1977	3.00	20.48	23.48	7.29	2.19	14.00
May 1977	0.36	34.96	35.32	8.08	4.12	23.12
June 1977	3.01	42.69	45.70	9.95	5.80	29.95
July 1977	1.29	56.20	57.49	8.56	2.39	46.54
August 1977	1.77	53.73	55.50	7.96	2.47	45.07
September 1977	3.35	46.88	50.23	15.40	0.70	34.13
ANNUAL	22.25	302.37	324.62	71.80	22.89	229.93
% of Input	6.85	93.15	100.00	22.12	7.05	70.83

* Based on mean literature values for Michigan.



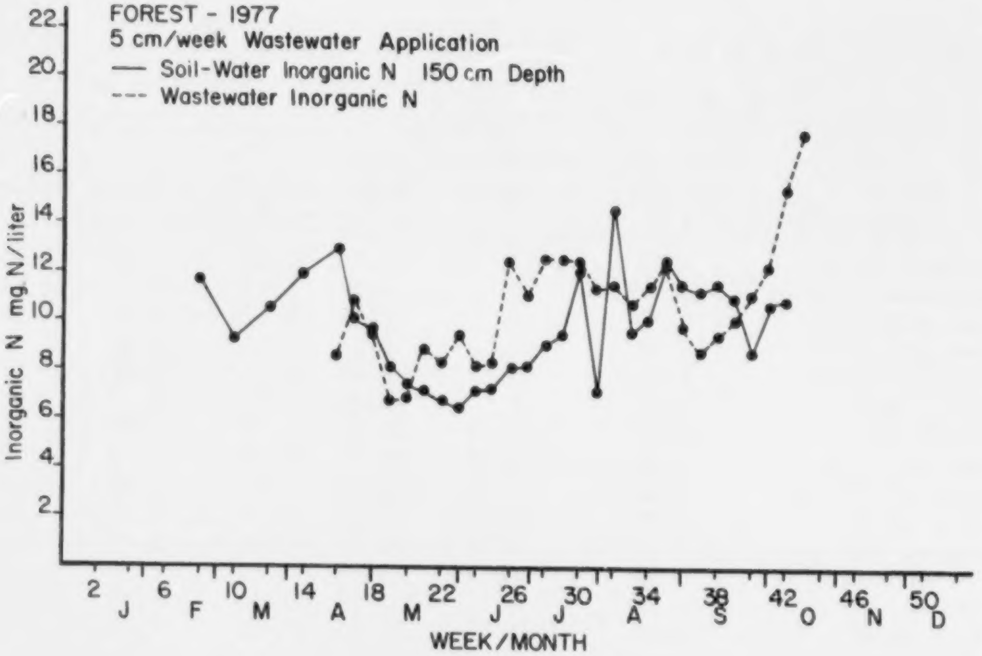


Figure 7-3. Inorganic N concentrations in soil-water at the 150 cm depth for the 5 cm/week forest wastewater application area.

period (May to November) and would indicate that any evaluation of land treatment of wastewater based on the first year of application is meaningless. Similar lag times were reported for the Pennsylvania studies.[5] Thus, all mass balances presented here are for the 1976-77 water year after the soil-water was in equilibrium with input wastewater chloride concentrations.

The mass balance for inorganic N for the 10 cm/week wastewater application site (TABLE 7-3) presents a markedly different picture. Retention of nitrogen (wastewater renovation) is 71%. As discussed above, all runoff probably originated from this site. Thus, 22% of input inorganic N ran off from this site (TABLE 7-3) representing an annual loss of 72 kg/ha. The 71% retention is probably the result of denitrification on this water logged site since inorganic N concentrations at the 150 cm output depth were much lower than input concentrations (Figure 7-4). Cl/N ratios support this contention. The Cl/N ratio varied between 5 and 10 for wastewater input in 1976 and 1977. The Cl/N ratio increased only slightly to between 6 and 14 at the 150 cm depth on the 5 cm/week site indicating little on-site retention; but it increased to 30 for the 10 cm/week site by the end of 1976, and it increased to 240 by the end of 1977, indicating substantial on-site retention of inorganic N. Thus, this site appears to be very efficient at wastewater renovation based only on concentration, but this efficiency is achieved at the cost of high runoff losses of N (and P as will be discussed later).

While the above calculations include all inorganic N, almost all input and output of inorganic N was as NO_3-N (Figure 7-5) although NH_4-N was a significant portion of input on certain occasions (TABLE 7-4).

Organic N mass balances for the 5 and 10 cm/week wastewater sites (TABLES 7-5 and 7-6) show that the 5 cm/week site retains most of the organic N (87%) with only 13% of input leaching to groundwater. The 10 cm/week site loses 58% or 66 kg organic N/ha in runoff, so retention is lower (38%). Only 4% leaches past the 150 cm depth as organic N. The retained N for both sites must have been immobilized as organic N or mineralized to inorganic N and stored in soil solution or lost by denitrification. Runoff losses of organic N from the 10 cm/week site are similar to water losses (TABLE 7-7) indicating little denitrification, vegetation uptake,

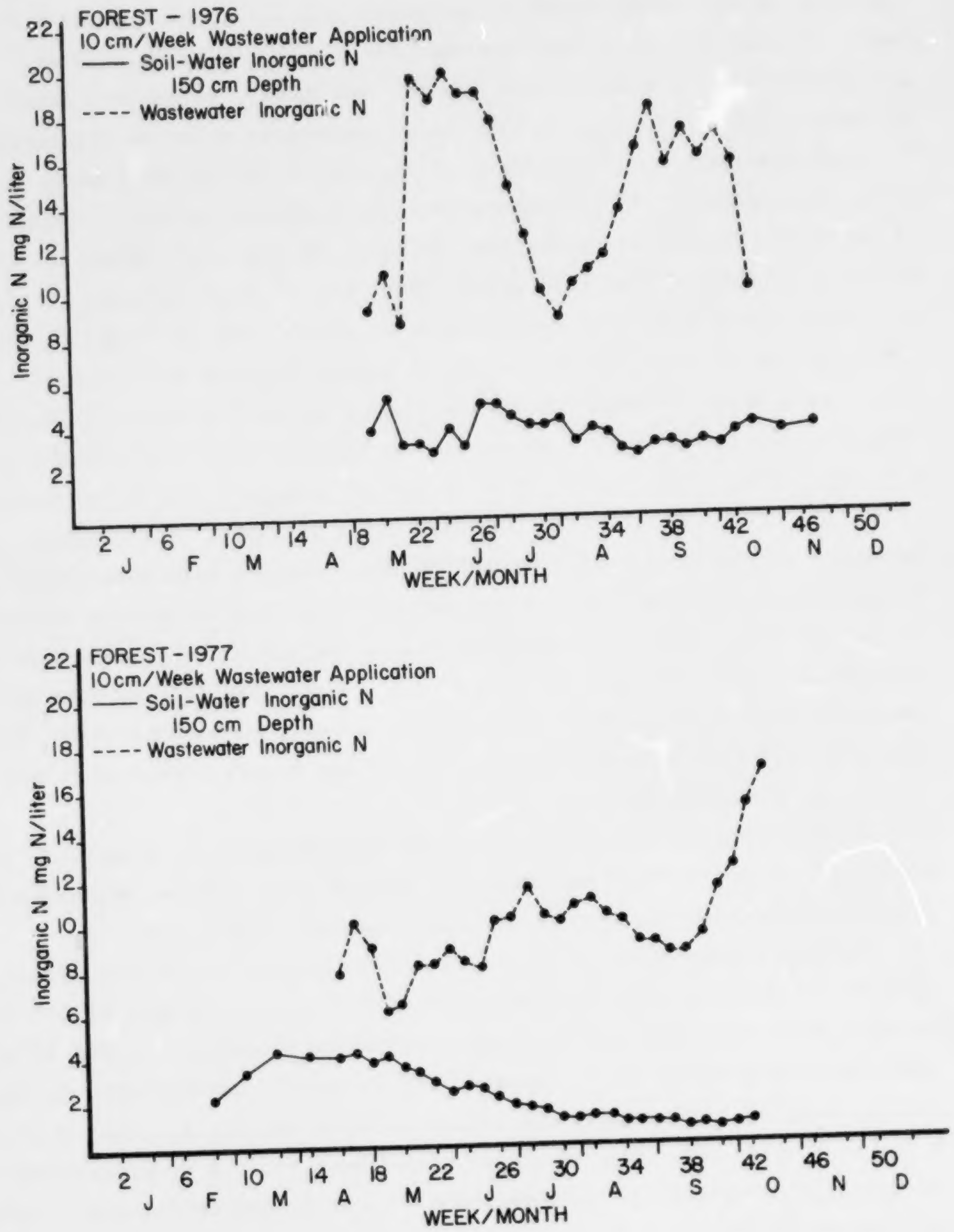


Figure 7-4: Inorganic N concentrations in soil-water at the 150 cm depth for the 10 cm/week forest wastewater application area.

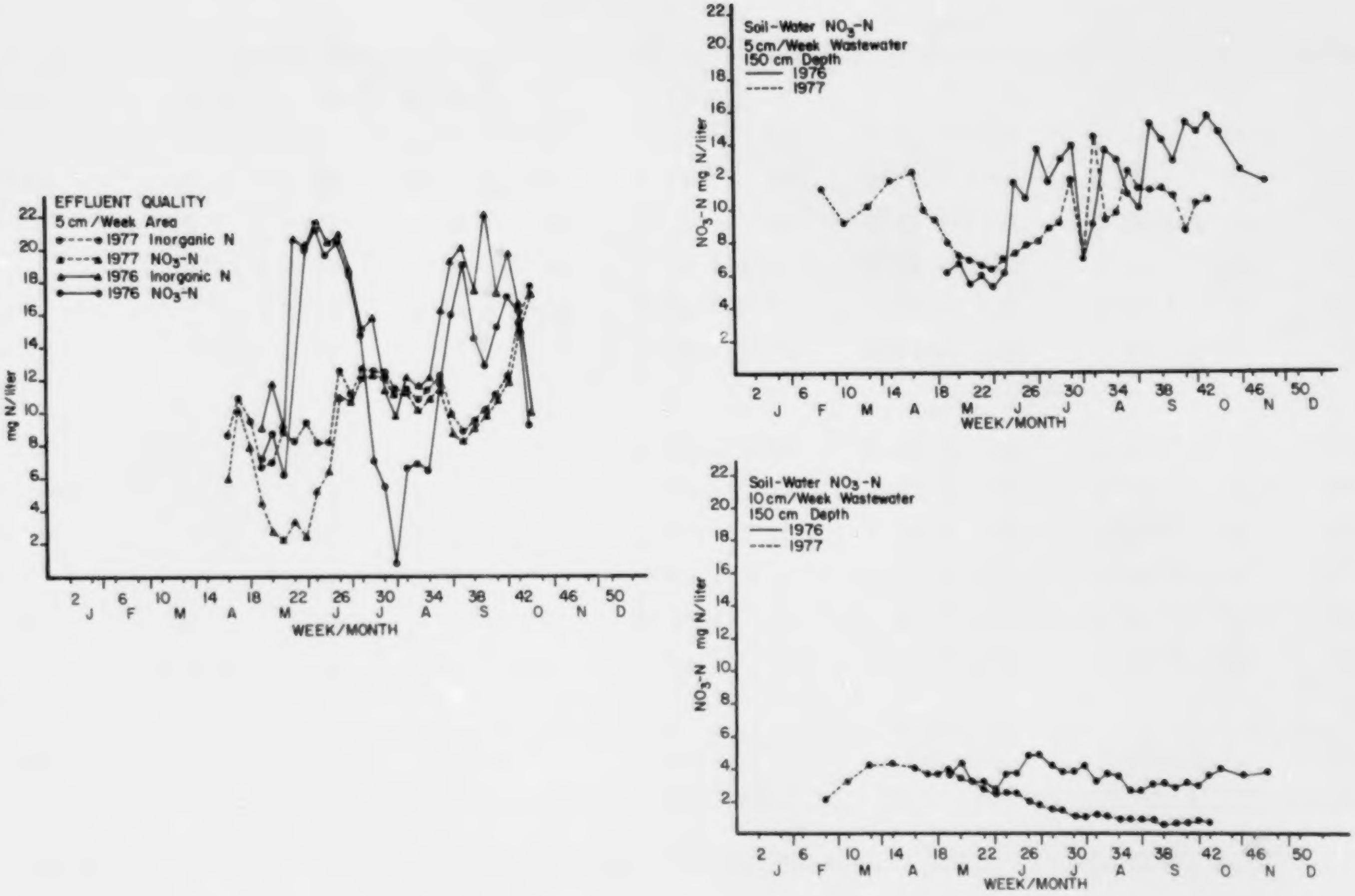


Figure 7-5: Concentrations of nitrate and total inorganic N in wastewater input and nitrate-N in soil-water samples for the forested sites.

TABLE 7-4. MONTHLY AVERAGE WASTEWATER INPUT CONCENTRATIONS FOR THE 5 CM/WEEK SPRAY SITE (VALUES IN MG/ℓ)

Month	NO_3-N	NO_2-N	NH_4-N	Organic N	Total P	Chloride
1976						
May	10.60 ± 6.24	-- --	1.88 ± 1.40	1.32 ± .47	3.06 ± .80	91 ± 12
June	20.07 ± 1.20	0.03 ± .03	0.36 ± .28	1.02 ± .37	3.91 ± .58	101 ± 10
July	7.89 ± 5.44	2.28 ± 2.84	4.66 ± 3.84	0.70 ± .43	1.63 ± .56	119 ± 24
August	8.81 ± 3.83	0.99 ± .99	3.81 ± 2.10	0.78 ± .49	3.73 ± .71	116 ± 18
September	15.51 ± 3.15	1.41 ± 2.05	2.05 ± 1.76	1.05 ± .67	4.06 ± .58	132 ± 15
October	14.21 ± 6.81	0.12 ± .14	1.13 ± 1.62	0.99 ± .75	3.61 ± 2.21	113 ± 3
1977						
April	8.13 ± 2.61	0.11 ± .04	1.50 ± 1.47	1.77 ± .76	3.30 ± .56	117 (1)
May	4.32 ± 2.38	0.17 ± .05	3.60 ± 2.19	2.41 ± .99	2.55 ± 1.43	122 ± 12
June	4.53 ± 1.95	0.34 ± 2.30	3.45 ± 2.45	6.26 ± 4.28	2.27 ± 1.84	128 ± 9
July	12.33 ± 1.85	0.30 ± .32	0.07 ± .05	3.29 ± 1.72	3.50 ± 2.61	123 ± 21
August	11.23 ± 1.24	0.32 ± .19	0.13 ± .08	3.13 ± 2.18	2.55 ± .88	105 ± 15
September	9.01 ± .75	0.49 ± .31	0.14 ± .09	2.77 ± 1.43	2.29 ± .76	114 ± 21
October	13.26 ± 2.58	0.22 ± .15	0.12 ± .10	2.74 ± .78	3.80 ± .71	131 ± 12

TABLE 7-5. MASS BALANCE FOR ORGANIC NITROGEN FOR THE 5 CM/WEEK FOREST IRRIGATION SITE (VALUES IN KG/HA)

Month	Precipitation*	Wastewater Irrigation	Total Input	Recharge	Retention
October 1976	1.54	1.73	3.27	0.86	2.41
November 1976	0.60	0	0.60	0.09	0.51
December 1976	0.39	0	0.39	0.04	0.35
January 1977	0.28	0	0.28	0.04	0.24
February 1977	4.71	0	4.71	0.08	4.63
March 1977	2.08	0	2.08	0.19	1.89
April 1977	3.04	2.05	5.09	0.94	4.15
May 1977	0.36	5.59	5.95	0.66	5.29
June 1977	3.05	16.34	19.39	2.00	17.39
July 1977	1.31	8.60	9.91	0.83	9.08
August 1977	1.79	8.17	9.96	1.46	8.50
September 1977	3.40	7.24	10.64	2.51	8.13
ANNUAL	22.55	49.72	72.27	9.70	62.57
% of Input	31.20	68.80	100.00	13.42	86.58

* Calculated from mean inorganic N data from Michigan by assuming that 50.34% of total N input is organic N (Hoeft *et al.*, 1972).[41]

TABLE 7-6. MASS BALANCE FOR ORGANIC NITROGEN FOR THE 10 CM/WEEK FOREST IRRIGATION SITE (VALUES IN KG/HA)

Month	Precipitation*	Wastewater Irrigation	Total Inputs	Runoff	Recharge	Retention
October 1976	1.54	3.53	5.07	5.46	0.35	-0.74
November 1976	0.60	0	0.60	0.18	0	0.42
December 1976	0.39	0	0.39	0	0.04	0.35
January 1977	0.28	0	0.28	0	0.03	0.25
February 1977	4.71	0	4.71	0	0.06	4.65
March 1977	2.08	0	2.08	2.03	0	0.05
April 1977	3.04	5.37	8.41	8.43	0.25	-0.27
May 1977	0.36	8.85	9.21	10.17	0.57	-1.53
June 1977	3.05	28.37	31.42	8.42	1.16	21.84
July 1977	1.31	15.50	16.81	8.31	0.70	7.80
August 1977	1.79	13.04	14.83	8.29	0.94	5.60
September 1977	3.40	16.82	20.22	14.93	0.33	4.96
ANNUAL	22.55	91.48	114.03	66.22	4.43	43.38
% of Input	19.78	80.22	100.00	58.07	3.88	38.04

* Calculated from mean inorganic N data for Michigan by assuming that 50.34% of total N input is organic N (Hoeft *et al.*, 1972).[41]

TABLE 7-7. WATER BUDGET FOR THE 10 CM/WEEK FOREST IRRIGATION SITE (VALUES IN m^3/ha)

Month	Precipitation	Wastewater Irrigation	Total Inputs	Evapotranspiration	Runoff	Retention
October 1976	520.7	3,497.6	4,018.3	285.0	2,570	1,164
November 1976	201.9	0	201.9	0	468	-266
December 1976	129.5	0	129.5	0	0	130
January 1977	96.5	0	96.5	0	0	96
February 1977	159.2	0	159.2	0	6	150
March 1977	701.0	0	701.0	184.5	945	-428
April 1977	1,027.9	2,304.2	3,332.1	504.0	2,306	522
May 1977	124.5	4,660.1	4,784.6	1,096.2	2,554	1,114
June 1977	1,030.4	5,244.1	6,274.5	1,071.0	2,921	2,282
July 1977	442.0	5,217.9	5,659.9	1,464.9	2,645	1,549
August 1977	607.1	5,217.6	5,824.7	1,183.1	2,457	2,185
September 1977	1,148.1	5,208.6	6,356.7	811.2	4,755	791
TOTALS	6,188.8	31,350.1	37,538.9	6,599.9	21,627	9,289
% of Inputs	16.49	83.51	100.0	17.58	57.61	24.74

or soil storage has occurred prior to runoff. On the 5 cm/week site, 70% of input water is recharged (TABLE 7-8) while only 13% (10 kg N/ha) of organic N percolates to groundwater (TABLE 7-5). Thus, this site is efficient at organic N removal.

On a total N basis, the 5 cm/week wastewater application area received 262 kg N/ha in the 1976-77 water year, retained 90 kg N/ha (34.5%), and lost 172 kg N/ha (65.5%) to the groundwater by leaching. The 90 kg N/ha is equivalent to an average of about 4.5 μg/g stored in the 150 cm soil profile as mineral N. The average NO_3-N stored in the soil profile at the end of 1976 was 5.8 μg/g (see TABLE 7-12 in discussion of soil samples below), so the retention appears reasonable. The 10 cm/week area received 439 kg N/ha, retained 273 kg N/ha (62%), lost 27 kg N/ha (6%) to the groundwater by leaching, and lost 138 kg N/ha (31%) in runoff. Retention also includes denitrification losses so is to some extent a misnomer but does indicate the capacity of the site for wastewater renovation. Thus, the 5 cm/week site is not very efficient at removal of N from wastewater (34.5%) while the 10 cm/week area is efficient (62%) probably due to denitrification on this water logged site. However, this efficiency is achieved at the cost of substantial runoff losses of nitrogen (138 kg N/ha/yr) and phosphorus as will be discussed later. It probably also is achieved at the cost of reduced tree growth and eventual death (this is being studied now) because of the anaerobic soils. Thus, these forests do not appear to be a reasonable place to recycle wastewater with nitrogen concentrations in excess of 10 mg N/ℓ.

Phosphorus

Mass balances for phosphorus for both the 5 and 10 cm/week wastewater irrigation sites indicate excellent site retention of phosphorus (TABLES 7-9 and 7-10). This retention approaches 97% for the 5 cm/week site where most water percolated to groundwater (TABLE 7-9). Retention for the 10 cm/week irrigation site is only 66% with 33% of the added total P being lost in runoff (TABLE 7-10). In fact, the flow weighted mean concentration in runoff was 1.04 mg P/ℓ for the summer irrigation period and 0.90 mg P/ℓ for the entire year. Peak concentrations in runoff often exceeded 1.0 mg P/ℓ

TABLE 7-8. WATER BUDGET FOR THE 5 CM/WEEK FOREST IRRIGATION SITE (VALUES IN m^3/ha)

Month	Precipitation	Wastewater Irrigation	Total Inputs	Evapotranspiration	Recharge
October 1976	520.7	1,747.5	2,268.2	285.0	1,983
November 1976	201.9	0	201.9	0	202
December 1976	129.5	0	129.5	0	130
January 1977	96.5	0	96.5	0	96
February 1977	159.2	0	159.2	0	159
March 1977	701.0	0	701.0	184.5	517
April 1977	1,027.9	1,157.8	2,185.7	504.0	1,682
May 1977	124.5	2,321.1	2,445.6	1,096.2	1,349
June 1977	1,030.4	2,609.7	3,640.1	1,071.0	2,570
July 1977	422.0	2,613.2	3,055.2	1,464.9	1,590
August 1977	607.1	2,608.8	3,215.9	1,183.1	2,033
September 1977	1,148.1	2,613.5	3,761.6	811.2	2,950
TOTALS	6,188.8	15,671.6	21,860.4	6,599.9	15,261
% of Input	28.31	71.69	100.0	30.19	69.81

TABLE 7-9. MASS BALANCE BUDGET FOR TOTAL PHOSPHORUS FOR THE 5 CM/WEEK FOREST IRRIGATION SITE (VALUES IN KG/HA)

Month	Precipitation*	Wastewater Irrigation	Total Input	Recharge	Retention
October 1976	0.014	6.308	6.322	0.151	6.171
November 1976	0.006	0	0.006	0.009	-0.003
December 1976	0.004	0	0.004	0.003	0.001
January 1977	0.003	0	0.003	0.003	0
February 1977	0.004	0	0.004	0.008	-0.004
March 1977	0.019	0	0.019	0.018	0.001
April 1977	0.028	3.821	3.849	0.076	3.773
May 1977	0.003	5.919	5.922	0.066	5.856
June 1977	0.028	5.924	5.952	0.252	5.700
July 1977	0.012	9.146	9.158	0.162	8.996
August 1977	0.016	6.652	6.668	0.222	6.446
September 1977	0.031	5.984	6.015	0.549	5.466
ANNUAL	0.168	43.754	43.922	1.519	42.403
% of Input	0.38	99.62	100.000	3.46	96.54

* Based on literature value of 0.027 mg P/ℓ for Michigan.

TABLE 7-10. MASS BALANCE FOR TOTAL PHOSPHORUS FOR THE 10 CM/WEEK FOREST IRRIGATION SITE (VALUES IN KG/HA)

Month	Precipitation*	Wastewater Irrigation	Total Inputs	Runoff	Recharge	Retention
October 1976	0.014	11.717	11.731	3.422	0.034	8.275
November 1976	0.006	0	0.006	0.572	0	-0.566
December 1976	0.004	0	0.004	0	0.008	-0.004
January 1977	0.003	0	0.003	0	0.005	-0.002
February 1977	0.004	0	0.004	0.125	0.007	-0.128
March 1977	0.019	0	0.019	0.785	0	-0.766
April 1977	0.028	7.604	7.632	4.138	0.025	3.469
May 1977	0.003	11.883	11.886	5.155	0.076	6.655
June 1977	0.028	11.904	11.932	3.244	0.169	8.519
July 1977	0.012	18.263	18.275	3.101	0.146	15.028
August 1977	0.016	13.305	13.321	2.880	0.122	10.319
September 1977	0.031	11.928	11.959	5.573	0.051	6.335
ANNUAL	0.168	86.604	86.772	28.995	0.643	57.134
% of Input	0.19	99.81	100.000	33.42	0.74	65.84

for this hydraulically overloaded site. While this deliberate water logging promoted denitrification, it resulted in significant losses of total P (29 kg/ha/yr) at concentrations in excess of Michigan standards for wastewater discharge. Thus, excessive irrigation of a site to promote denitrification would require a very delicate balancing act with irrigation at levels just high enough to maintain soil saturation but not high enough to yield runoff. Perhaps, irrigation on a daily and site-specific basis could achieve this goal, but the intensive monitoring and management required is likely to make this technique unacceptable to system operators.

Monthly total P concentrations at the 150 cm depth in both irrigation areas were low and similar to non-irrigated control levels (TABLE 7-11) through most of the year. There was a trend towards slightly elevated concentrations late in the year in the irrigated areas, but these concentrations were still low. Thus, on both a mass balance and concentration basis, these forested sites did an excellent job of removing P from percolated wastewater. Management of forested systems in such a manner that little or no runoff occurs would result in acceptable removal of P from wastewater. Similar results have been reported by numerous other studies for a wide variety of forest and soil types.[2,4,7,8,10,14,16,19-21,23-26]

TABLE 7-11. MONTHLY WASTEWATER INPUT AND OUTPUT (150 CM DEPTH) TOTAL P CONCENTRATIONS FOR THE FORESTED SITES (ALL VALUES IN MG P/ℓ)

Month	Wastewater Input	Non-Irrigated Control	5 cm/week Wastewater Irrigation	10 cm/week Wastewater Irrigation
October 1976	3.61	N.S.*	0.076	0.029
November 1976	--	0.028	0.045	0.048
December 1976	--	N.S.	0.022	0.063
January 1977	--	N.S.	0.036	0.053
February 1977	--	N.S.	0.049	0.043
March 1977	--	0.042	0.035	0.044
April 1977	3.30	0.040	0.045	0.047
May 1977	2.55	0.064	0.049	0.068
June 1977	2.27	0.042	0.098	0.074
July 1977	3.50	N.S.	0.102	0.094
August 1977	2.55	N.S.	0.109	0.056
September 1977	2.29	N.S.	0.186	0.065

* N.S. designates No Sample, soil too dry.

The primary mechanism of this removal appears to be sorption on soil particles although some increased growth and P uptake has been documented.[22]

Soil Sampling

Soil sampling was conducted at each of the lysimeter sites before irrigation began and after it ceased in 1976. Wastewater had not been applied to these sites long enough to expect major changes in soil chemistry. Minor changes would be masked by the variability normally associated with soil analysis from a glaciated area. Thus, it is not too surprising that few significant trends are apparent in these soil analyses (TABLES 7-12 to 7-16). There is a possible trend of increased P in the 0-15 cm increment (TABLE 7-13) and a significant increase in sodium and chloride at all depths on the wastewater irrigated sites (TABLES 7-14, 7-16), but no other clear cut trends are apparent. These data provide a baseline for studies of long-term changes in soil chemistry.

TABLE 7-12. NITRATE-NITROGEN ANALYSES OF SOILS FROM THE FOREST WASTEWATER IRRIGATION STUDY

Depth-cm	0 cm/week 1975	 1976	5 cm/week 1975	 1976	10 cm/week 1975	 1976
			NITRATE-NITROGEN (μg/g dry soil)			
0- 15	14.4	8.3	14.5	11.6	5.3	6.5
15- 30	2.9	6.0	5.4	6.0	11.3	4.8
30- 45	2.2	4.3	6.0	5.4	5.4	4.4
45- 60	1.8	3.8	1.8	5.6	1.7	4.3
60- 75	2.2	3.8	2.9	5.3	2.5	4.1
75- 90	1.8	3.9	1.7	4.9	3.1	3.9
90-105	2.1	3.1	1.3	4.7	2.3	3.9
105-120	1.5	3.0	1.7	5.7	1.7	4.4
120-135	2.4	3.3	1.8	4.3	1.8	4.1
135-150	2.0	3.4	1.8	4.5	1.1	3.7
AVERAGE	3.3	4.3	3.9	5.8	3.6	4.4
			NITRATE NITROGEN (μg/mℓ of soil-water)			
0- 15	34.6	46.9	48.1	27.9	17.7	14.7
15- 30	14.1	59.4	34.5	26.5	57.0	21.7
30- 45	9.8	61.2	52.1	32.9	38.7	26.6
45- 60	8.2	65.0	10.0	37.2	11.5	24.4
60- 75	10.2	54.4	22.4	36.3	14.6	22.4
75- 90	9.0	78.5	13.8	33.6	16.6	24.2
90-105	9.6	57.9	9.1	35.0	12.5	24.0
105-120	8.1	50.5	12.9	36.2	8.5	29.2
120-135	10.8	47.8	11.9	34.6	11.9	27.0
135-150	9.9	37.8	12.2	33.5	6.8	25.5
AVERAGE	12.4	55.9	22.7	33.4	19.6	23.9

TABLE 7-13. BRAY EXTRACTABLE PHOSPHORUS AND AMMONIUM-NITROGEN ANALYSES OF SOILS FROM THE FOREST WASTEWATER IRRIGATION STUDY. VALUES IN µg/g DRY SOIL. (NOTE: NO 1975 DATA ON AMMONIUM-NITROGEN)

	0 cm/week		5 cm/week		10 cm/week	
Depth-cm	1975	1976	1975	1976	1975	1976
			PHOSPHORUS			
0- 15	14.2	13.2	17.4	25.0	17.9	29.9
15- 30	7.1	9.1	11.6	13.1	12.8	12.6
30- 45	8.0	7.2	8.5	8.9	5.2	5.4
45- 60	5.3	6.6	5.7	6.8	2.6	3.1
60- 75	5.5	7.3	6.4	7.4	2.2	2.1
75- 90	5.8	6.4	6.0	8.2	1.8	1.3
90-105	5.5	5.1	4.8	4.5	1.3	1.1
105-120	3.0	2.8	4.1	2.1	1.0	1.1
120-135	2.2	2.6	3.9	1.8	1.0	1.0
135-150	1.4	2.3	2.7	2.2	1.0	.8
AVERAGE	5.8	6.3	7.1	8.0	4.7	5.8
			AMMONIUM-NITROGEN			
0- 15	--	7.6	--	11.5	--	11.9
15- 30	--	3.7	--	5.0	--	4.4
30- 45	--	2.5	--	3.8	--	2.9
45- 60	--	2.2	--	2.8	--	2.8
60- 75	--	2.1	--	2.7	--	2.8
75- 90	--	2.3	--	2.6	--	2.5
90-105	--	1.9	--	2.5	--	2.5
105-120	--	2.0	--	2.4	--	2.3
120-135	--	2.2	--	2.1	--	2.6
135-150	--	1.9	--	2.3	--	2.2
AVERAGE	--	2.8	--	3.8	--	3.7

TABLE 7-14. SODIUM AND POTASSIUM ANALYSES OF SOILS FROM THE FOREST WASTEWATER IRRIGATION STUDY (VALUES IN μg/g DRY SOIL)

	0 cm/week		5 cm/week		10 cm/week	
Depth-cm	1975	1976	1975	1976	1975	1976
			SODIUM			
0- 15	39.8	56.6	56.1	158.0	35.8	177.4
15- 30	32.8	46.7	46.5	90.3	28.8	101.7
30- 45	39.8	46.3	47.6	74.9	29.9	77.0
45- 60	40.5	42.7	46.2	82.8	29.7	78.2
60- 75	38.9	52.3	39.8	78.4	35.5	85.4
75- 90	36.6	59.3	40.8	80.9	39.0	128.3
90-105	50.4	59.4	40.2	78.6	38.5	89.4
105-120	49.4	63.1	41.7	89.9	42.5	90.5
120-135	53.5	64.2	48.6	89.1	43.7	92.9
135-150	60.2	72.4	46.4	81.6	42.5	84.2
AVERAGE	44.2	56.3	45.4	90.4	36.6	100.5
			POTASSIUM			
0- 15	80.3	90.8	62.9	96.4	58.9	72.3
15- 30	44.1	51.0	32.4	55.5	47.9	43.6
30- 45	59.3	35.8	39.7	37.0	38.4	39.4
45- 60	62.2	40.2	48.6	55.7	49.3	42.3
60- 75	66.8	49.2	44.6	46.9	52.2	43.3
75- 90	48.8	60.5	41.8	47.6	44.1	38.6
90-105	52.1	53.0	35.5	43.4	44.4	36.5
105-120	48.8	46.9	36.8	49.7	46.6	35.0
120-135	47.7	51.9	40.7	43.5	37.4	35.1
135-150	52.0	50.3	38.0	42.6	31.4	32.2
AVERAGE	56.2	53.0	42.1	51.8	45.1	41.8

TABLE 7-15. CALCIUM AND MAGNESIUM ANALYSES OF SOILS FROM THE FOREST WASTEWATER IRRIGATION STUDY (VALUES IN μg/g DRY SOIL)

Depth-cm	0 cm/week 1975	0 cm/week 1976	5 cm/week 1975	5 cm/week 1976	10 cm/week 1975	10 cm/week 1976
			CALCIUM			
0- 15	1808.3	2020.3	1941.3	2497.1	2284.4	2386.6
15- 30	679.3	901.5	795.2	1575.7	982.3	1094.5
30- 45	683.9	742.5	998.1	824.9	905.9	946.8
45- 60	803.2	798.2	973.1	1007.1	1082.6	1137.7
60- 75	858.6	927.3	901.4	945.0	1326.1	1777.2
75- 90	996.8	1385.4	956.5	1192.5	1466.3	2201.5
90-105	1396.0	1298.3	1304.2	1359.9	2094.1	2649.4
105-120	1873.0	1935.8	1522.5	2098.5	2440.8	2970.1
120-135	1840.8	2076.4	2211.6	2013.8	2938.0	3047.4
135-150	2771.3	2577.0	1966.8	2212.4	2719.7	2967.0
AVERAGE	1371.1	1466.3	1357.1	1572.7	1824.0	2117.8
			MAGNESIUM			
0- 15	186.3	214.9	223.5	330.6	220.3	351.0
15- 30	95.3	87.5	105.7	218.3	128.4	180.0
30- 45	114.1	86.0	138.8	109.0	175.5	213.1
45- 60	160.9	128.5	180.5	158.1	257.7	249.0
60- 75	187.1	188.2	218.5	168.7	285.9	251.1
75- 90	189.7	236.5	191.0	206.0	260.1	221.9
90-105	198.9	236.1	180.1	206.5	269.2	201.8
105-120	243.3	231.7	163.1	208.1	267.6	190.3
120-135	234.3	239.5	199.9	173.1	204.1	179.6
135-150	469.1	279.9	169.6	166.6	168.9	140.5
AVERAGE	207.9	192.9	177.1	194.5	223.8	217.8

TABLE 7-16. CHLORIDE ANALYSES OF SOILS FROM THE FOREST WASTEWATER IRRIGATION STUDY

	0 cm/week		5 cm/week		10 cm/week	
Depth-cm	1975	1976	1975	1976	1975	1976
			CHLORIDE (µg/g dry soil)			
0- 15	9.8	16.9	8.2	47.5	11.2	46.8
15- 30	7.4	14.3	8.2	32.0	9.2	30.3
30- 45	8.2	12.5	8.1	26.0	11.2	27.1
45- 60	7.5	13.1	8.4	27.0	10.0	26.6
60- 75	9.7	12.8	11.0	28.7	10.2	29.4
75- 90	7.1	13.8	8.8	26.2	11.4	30.4
90-105	9.6	12.7	11.4	26.1	10.9	29.5
105-120	7.4	14.4	11.2	31.5	10.2	26.5
120-135	10.0	14.6	13.9	28.3	12.0	27.3
135-150	9.3	16.3	9.5	28.7	10.3	23.3
AVERAGE	8.6	14.1	9.9	30.2	10.7	29.7
			CHLORIDE (µg/mℓ of soil-water)			
0- 15	26.9	99.1	30.4	113.7	40.9	106.5
15- 30	39.1	144.2	48.8	140.2	50.5	135.9
30- 45	37.6	173.4	64.9	163.8	76.0	158.9
45- 60	35.3	217.6	52.5	165.6	64.6	150.1
60- 75	44.8	183.5	81.2	183.0	59.0	160.0
75- 90	37.0	248.4	68.9	170.7	64.0	183.2
90-105	43.3	227.4	75.3	173.9	64.0	173.6
105-120	40.2	236.1	78.5	186.2	54.0	171.4
120-135	48.3	219.4	93.4	210.9	78.4	174.5
135-150	45.6	191.3	67.8	212.9	67.3	156.8
AVERAGE	39.8	194.0	66.2	172.1	61.9	157.1

Runoff Sampling

Data for loads of nutrients in runoff from the entire 18.4 ha sub-watershed are included in TABLES 7-17 to 7-21. Loads were calculated using the Beale ratio estimator technique adopted for all IJC studies. Only 8.5 ha of this watershed is forested. Inputs from an upstream 7.73 ha sub-watershed (TABLES 9-2 to 9-6) and 2.2 ha of downstream oldfield areas are included. However, almost all of the runoff from 7.73 ha upstream station occurred during spring runoff (97%) and early summer (3%). Water budget calculations (TABLE 7-1) for non-irrigated forests suggest that any runoff from the non-sprayed forested areas occurred during April. Thus, almost all runoff from the 18.4 ha "forested" sub-watershed except during the spring period must have occurred as a result of wastewater irrigation. Furthermore, water budget and chloride dilution calculations suggest that almost all of this water originated from the 1.2 ha site irrigated with 10 cm/week of wastewater. In mass balance calculations (TABLES 7-2,7-3,7-5,7-6,7-9,7-10), upstream inputs from the 7.73 ha baseline watershed were subtracted and the remainder assigned to the 10 cm/week spray site. Only 55% of water discharge originated from the forest during spring runoff (58% of total area) so all areas may have been contributing during this season. During other seasons, runoff had to have originated primarily from the spray sites. The monthly mass balances (TABLES 7-2,7-3,7-5,7-6, 7-9,7-10) are likely to be affected significantly only during March and April (92% of water from the 7.73 ha baseline watershed was discharged during this period) with corrections made for input from upstream areas and with the limited contribution expected from non-sprayed areas during March and April (TABLE 7-1), the annual loading calculations from the spray site must be substantially correct.

The unit area loads (TABLES 7-17 to 7-21) for this 18.4 ha sub-watershed are misleading since most of these loads originated from the 1.2 ha, 10 cm/week spray irrigation site. If this is the case, then maximum annual exports from this 1.2 ha site are correct as listed in the mass balances (TABLES 7-3,7-6,7-10).

TABLE 7-17. STREAM EXPORT OF MOLYBDATE REACTIVE PHOSPHORUS AND TOTAL PHOSPHORUS FROM THE 18.35 ha FORESTED AREA*

Season	EVENT FLOW		Non-Event Flow (kg)	Export Total (kg)	% Total	Unit Area Loads* (kg/ha)
	Rising Hydrograph (kg)	Descending Hydrograph (kg)				
MOLYBDATE REACTIVE PHOSPHORUS						
Fall, 1976	0.768 ± 0.002	1.944 ± 0.028	0.076 ± 0.000	2.788 ± 0.028	-----	0.152
Winter, 1976-77	0	0	0.031 ± 0.091	0.031 ± 0.091	-----	0.002
Spring Runoff, 1977	0.239 ± 0.001	1.894 ± 1.853	0.255 ± 0.094	2.388 ± 1.855	-----	0.130
Spring Post Runoff 1977	0.469 ± 0.000	ND**	0.279 ± 0.000	-----	-----	-----
Summer, 1977	ND	ND	ND	-----	-----	-----
Total 1976-77 Water Year	-----	-----	-----	-----	-----	-----
% of Total	-----	-----	-----	-----	-----	-----
TOTAL PHOSPHORUS						
Fall, 1976	0.529 ± .001	1.919 ± 0.015	0.138 ± 0.000	2.586 ± 0.015	6.98	0.141
Winter, 1976-77	0	0	0.369 ± 2.700	0.369 ± 2.700	1.00	0.020
Spring Runoff, 1977	0.309 ± .001	2.315 ± 2.026	0.445 ± 0.301	3.069 ± 2.048	8.28	0.167
Spring Post Runoff 1977	2.234 ± .648	8.156 ± 0.053	0.430 ± 0.348	10.820 ± 0.737	29.19	0.590
Summer, 1977	2.415 ± .059	9.746 ± 3.114	8.058 ± 0.000	20.219 ± 3.115	54.55	1.102
Total 1976-77 Water Year	5.487 ± .651	22.136 ± 3.715	9.440 ± 2.739	37.063 ± 4.662		2.019
% of Total	14.80	59.73	25.47			

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* Most runoff originated from the 1.2 ha, 10 cm/week wastewater irrigation site so unit area loads calculated for the entire site are misleading.

** ND = no data

TABLE 7-18. STREAM EXPORT OF NITRATE AND AMMONIA NITROGEN FROM THE 18.35 ha FORESTED AREA*

Season	EVENT FLOW Rising Hydrograph (kg)	EVENT FLOW Descending Hydrograph (kg)	Non-Event Flow (kg)	Export Total (kg)	% Total	Unit Area Loads* (kg/ha)
			NITRATE-NITROGEN			
Fall, 1976	2.82 ± 0.001	4.65 ± 0.10	0.011 ± 0.00	7.48 ± 0.10	9.45	0.408
Winter, 1976-77	0	0	0.18 ± 1.14	0.18 ± 1.14	0.23	0.010
Spring Runoff, 1977	0.42 ± 0.002	3.36 ± 0.58	1.73 ± 0.33	5.51 ± 0.66	6.96	0.300
Spring Post Runoff 1977	10.38 ± 2.46	4.84 ± 0.35	0.58 ± 0.00	15.80 ± 2.49	19.96	0.861
Summer, 1977	9.10 ± 0.35	37.85 ± 9.75	3.25 ± 1.80	50.21 ± 9.92	63.42	2.736
Total 1976-77 Water Year	22.72 ± 2.49	50.70 ± 9.78	5.74 ± 2.16	79.17 ± 10.31		4.315
% of Total	28.70	64.04	7.25			
			AMMONIA-NITROGEN			
Fall, 1976	0.003 ± .00001	0.070 ± .001	0.0008 ± 0.00	0.074 ± 0.001	1.33	0.004
Winter, 1976-77	0	0	0.0012 ± 0.00	0.001 ± 0.000	0.02	0.00006
Spring Runoff, 1977	0.121 ± .0006	0.373 ± .156	0.065 ± 0.048	0.559 ± 0.163	10.03	0.030
Spring Post Runoff 1977	0.355 ± .010	1.077 ± .019	0.110 ± 0.011	1.542 ± 0.024	27.66	0.084
Summer, 1977	1.308 ± .013	1.423 ± .092	0.667 ± 2.490	3.398 ± 2.492	60.96	0.185
Total 1976-77 Water Year	1.787 ± .016	2.943 ± .182	0.844 ± 2.490	5.574 ± 2.497	100.00	0.303
% of Total	32.06	52.80	15.14			

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* Most runoff originated from the 1.2 ha, 10 cm/week wastewater irrigation site so unit area loads calculated for the entire site are misleading.

TABLE 7-19. STREAM FXPORT OF NITRITE AND KJELDAHL NITROGEN FROM THE 18.35 ha FORESTED AREA *

Season	EVENT FLOW					
	Rising Hydrograph (kg)	Descending Hydrograph (kg)	Non-Event Flow (kg)	Export Total (kg)	% Total	Unit Area Loads* (kg/ha)
			NITRITE-NITROGEN			
Fall, 1976	0.067 ± .0004	0.136 ± .003	0.004 ± 0.000	0.207 ± 0.003	6.23	0.011
Winter, 1976-77	0	0	0.007 ± 0.000	0.007 ± 0.000	0.21	0.0004
Spring Runoff, 1977	0.120 ± .0007	0.205 ± .046	0.104 ± 0.053	0.429 ± 0.070	12.92	0.023
Spring Post Runoff 1977	0.149 ± .016	0.225 ± .023	0.060 ± 0.004	0.434 ± 0.028	13.07	0.024
Summer, 1977	0.569 ± .011	1.561 ± .566	0.114 ± 0.107	2.244 ± 0.576	67.57	0.122
Total 1976-77 Water Year	0.905 ± .019	2.127 ± .568	0.289 ± 0.119	3.321 ± 0.581		0.181
% of Totals	27.25	64.05	8.70	100.00		
			KJELDAHL-NITROGEN			
Fall, 1976	0.507 ± 0.0009	2.070 ± 0.011	0.149 ± 0.000	2.726 ± 0.011	2.76	0.149
Winter, 1976-77	0	0	0.472 ± 3.302	0.472 ± 3.302	0.48	0.026
Spring Runoff, 1977	2.045 ± 0.011	7.297 ± 2.549	1.529 + 0.450	10.871 ± 2.588	11.02	0.592
Spring Post Runoff 1977	12.276 ± 4.323	12.138 ± 0.119	2.554 ± 0.006	26.968 ± 4.325	27.35	1.470
Summer, 1977	6.094 ± 0.052	38.904 ± 4.200	12.578 ± 0.000	57.576 ± 4.200	58.39	3.138
Total 1976-77 Water Year	20.922 ± 4.323	60.409 ± 4.914	17.282 ± 3.333	98.613 ± 7.345		5.374
% of Totals	21.22	61.26	17.53			

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* Most runoff originated from the 1.2 ha, 10 cm/week wastewater irrigation site so unit area loads calculated for the entire site are misleading.

TABLE 7-20. STREAM EXPORT OF CHLORIDE AND SUSPENDED SOLIDS FROM THE 18.35 ha FORESTED AREA*

Season	EVENT FLOWS Rising Hydrograph (kg)	EVENT FLOWS Descending Hydrograph (kg)	Non-Event Flow (kg)	Export Total (kg)	% Total	Unit Area Loads* (kg/ha)
			CHLORIDE			
Fall, 1976	65.36 ± 0.15	246.50 ± 0.07	17.98 ± 0.00	329.84 ± 0.17	6.15	17.97
Winter, 1976-77	0	0	3.74 ± 12.48	3.74 ± 12.48	0.07	0.20
Spring Runoff '77	153.11 ± 0.76	527.93 ± 47.54	206.77 ± 20.39	887.81 ± 51.73	16.55	48.38
Spring Post Runoff 1977	461.89 ± 61.36	648.65 ± 11.23	121.22 ± 2.07	1231.76 ± 62.41	22.97	67.13
Summer, 1977	374.85 ± 8.63	1857.92 ± 98.56	677.39 ± 93.12	2910.16 ± 135.87	54.26	158.59
Total 1976-77 Water Year	1055.21 ± 61.97	3281.00 ± 110.00	1027.10 ± 96.16	5363.31 ± 158.71		292.28
% of Total	19.67	61.17	19.15			
			SUSPENDED SOLIDS			
Fall, 1976	11.25 ± 0.06	21.39 ± 0.39	1.14 ± 0.00	33.78 ± 0.39	-----	1.841
Winter, 1976-77	0	0	ND**	-----	-----	-----
Spring Runoff '77	ND	ND	ND	-----	-----	-----
Spring Post Runoff 1977	ND	ND	ND	-----	-----	-----
Summer, 1977	ND	ND	ND	-----	-----	-----
Total 1976-77 Water Year	-----	-----	-----	-----	-----	-----
% of Total	-----	-----	-----	-----	-----	-----

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* Most runoff originated from the 1.2 ha, 10 cm/week wastewater irrigation site so unit area loads calculated for the entire site are misleading.

** ND = no data

TABLE 7-21. STREAM EXPORT OF SODIUM AND CALCIUM FROM THE 18.35 ha FORESTED AREA*

Season	EVENT FLOWS Rising Hydrograph (kg)	EVENT FLOWS Descending Hydrograph (kg)	Non-Event Flow (kg)	Export Total (kg)	% Total	Unit Area Loads* (kg/ha)
			SODIUM			
Fall, 1976	48.95 ± 0.60	157.79 ± 2.13	ND	-----	-----	-----
Winter, 1976-77	0	0	0.367 ± 0.00	0.367 ± 0.00	-----	0.02
Spring Runoff, 1977	92.06 ± 3.66	188.06 ± 15.67	119.73 ± 36.57	399.85 ± 40.02	-----	21.79
Spring Post Runoff 1977	ND	ND	ND	-----	-----	-----
Summer, 1977	ND	ND	ND	-----	-----	-----
Total 1976-77 Water Year	-----	-----	-----	-----	-----	-----
% of Total	-----	-----	-----	-----	-----	-----
			CALCIUM			
Fall, 1976	44.00 ± 0.52	130.73 ± 0.17	ND	-----	-----	-----
Winter, 1976-77	0	0	2.20 ± 13.62	2.20 ± 13.62	-----	0.120
Spring Runoff, 1977	228.17 ± 9.09	530.66 ± 2.43	287.45 ± 91.57	1046.28 ± 92.05	-----	57.018
Spring Post Runoff 1977	ND	ND	ND	-----	-----	-----
Summer, 1977	ND	ND	ND	-----	-----	-----
Total 1976-77 Water Year	-----	-----	-----	-----	-----	-----
% of Total	-----	-----	-----	-----	-----	-----

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* Most runoff originated from the 1.2 ha, 10 cm/week wastewater irrigation site so unit area loads calculated for the entire site are misleading.

** ND = no data

CONCLUSIONS/REMEDIAL MEASURES

In conclusion, older hardwood forests are not reasonable places to practice wastewater irrigation if that wastewater has a higher concentration of inorganic N than the 10 mg NO_3-N/ℓ drinking water standard. Since municipal wastewater typically has concentrations in excess of the 10 mg N/ℓ standard, older forests should not be used for municipal wastewater irrigation. An exception to this would be wastewater from lagoon systems. Typically, aquatic plant production in lagoons raises the pH above 9.2, the pK of ammonia gas, and nitrogen is lost to the atmosphere as ammonia gas.[42] During periods predominated by plant decay (e.g., crash of algal blooms, self-shading and decreased water circulation as a result of high macrophyte production), nitrogen is lost as a result of denitrification under the existing anaerobic conditions. In either case, lagoons can be managed so that there is excellent removal of nitrogen (D. King, personal communication). Thus, a combined lake (lagoon)-land treatment system could utilize forests for wastewater irrigation without NO_3-N contamination of groundwater.

Also, excess application of wastewater can result in excellent denitrification as shown by results from the 10 cm/week site and as suggested by Kardos and Sopper for their hardwood site.[10] This excess application would have to be carefully controlled to prevent excessive runoff losses of N and P. The intensive management required for this option coupled with likely damage to tree growth and viability (unanswered questions at this time) make this option unattractive.

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SECTION 8

WINTER SPRAY IRRIGATION OF SECONDARY MUNICIPAL EFFLUENT IN MICHIGAN*

David E. Leland, David C. Wiggert, and Thomas M. Burton

INTRODUCTION

Eutrophication of surface waters in the United States has resulted in the establishment of stringent standards for point source nitrogen and phosphorus discharges. Secondary municipal wastewater treatment plants are major point sources and a number of physical, chemical, and biological tertiary treatment methods have been devised to enable plants to meet the new standards. Land application of sewage plant effluents has received considerable attention because of low energy requirements and potential for recycling nutrients and water. In northern climates where the growing season is of limited duration, land application during the winter months would result in savings in both land and lagoon storage and would add flexibility in management of land application systems. However, soil microorganism and plant activities which take up significant quantities of nitrogen and phosphorus from sewage effluents applied to the land[1,2,3] are reduced to negligible levels under cold winter conditions.

Data currently available on land application of sewage effluents during the winter in northern climates are insufficient for establishment of design and operating criteria for such systems. Studies conducted at Pennsylvania State University[4] and at the U.S. Army's Cold Region Research and Engineering Laboratory in New Hampshire[5] indicated that winter irrigation could be accomplished with excellent phosphorus removal. However, in the New Hampshire studies nitrogen was stored in the soil over the winter and was released in a large pulse after the soil warmed in the spring.[5]

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* This section has been accepted for publication in the Journal Water Pollution Control Federation.

Nitrogen application in the New Hampshire studies was primarily in the ammonium ion form which will sorb to soil particles. Nitrification apparently occurred when the soil warmed resulting in a large, pulsed loss of nitrogen as nitrate and would have resulted in groundwater contamination in an operating system. Runoff nutrient concentrations were minimum when soil percolation occurred in the Pennsylvania State system and maximum under frozen soil conditions.[4] Thus, soil frost penetration would require such systems to limit operation. Techniques need to be developed which will limit frost penetration and maintain soil infiltration and percolation. Also, further studies need to be conducted under the varied climatic conditions that occur in northern climates.

Water quality standards must be met even during winter operations. Regulations pursuant to Michigan Public Act 245 call for 80% phosphorus concentration reduction in surface discharge or a maximum monthly concentration of 1.0 mg P/ℓ. Groundwater supplies must be protected from nitrate contamination; therefore, the standard of 10 mg N/ℓ nitrate as called for in the National Interim Primary Drinking Water Regulations should not be exceeded in the groundwater at the spray site.

A year round spray irrigation study was conducted from December, 1975, to March, 1977, on a 3 ha unmodified oldfield subwatershed in southern Michigan using secondary municipal effluent from the city of East Lansing, Michigan. The purpose of this study was to provide the data base necessary for establishment of design and operating criteria for winter spray irrigation of secondary sewage effluents. Seasonal mass balances were constructed for nitrogen, phosphorus, chloride, and water, and were used to compare winter wastewater renovation efficiencies with efficiencies achieved during active growing seasons. Mass balances for the entire study period are discussed in this paper. The winter 1976-77 data are emphasized since these represent data collected after the newly constructed East Lansing wastewater treatment facility went on-line and are indicative of routine operation using secondary effluent.

DESCRIPTION OF THE STUDY AREA

This study was conducted on a 3 ha oldfield subwatershed on the Water Quality Management Project (WQMP) spray irrigation facility located on the

Michigan State University campus. The WQMP is operated by the Institute of Water Research at Michigan State and consists of a series of four man-made 1.8 m deep lakes with a total surface area of 16.2 ha and a 58 ha land irrigation site. During the 1976 growing season, the lakes received 1890 m^3/day (0.5 MGD) of unchlorinated secondary effluent from the East Lansing sewage treatment plant. An additional 1100 to 1500 m^3/day of secondary effluent were received, chlorinated and spray irrigated on several specific research projects on the WQMP irrigation site. During the winter of 1975-1976, the new East Lansing sewage treatment plant had not been completed. Wastewater from the old, overloaded plant was used to fill the four lakes with wastewater effluent which had undergone phosphorus removal. Winter irrigation was from the first lake in the series and represented stored tertiary wastewater. Thus, the 1975-76 winter data do not represent loadings typical of secondary effluent. The WQMP started receiving secondary effluent with no phosphorus removal from the section of the East Lansing plant associated with the WQMP in April, 1976. All irrigation of the winter spray area from that time has been with chlorinated secondary effluent.

The 3 ha area selected for study represents a discrete subwatershed unit with well defined surface topography and is shown in Figure 8-1. An intensive soil survey of this site in 1976[6] showed that 70% of the site consists of Miami-Marlette soil, a loam, silt loam or silt glacial till while the remainder of the site consists of sand, sandy clay loam and clay loam soil. Extreme variation of soil type exists both laterally and vertically with numerous sand and clay lenses.

Vegetation on this old abandoned field is dominated by goldenrod (Solidago canadensis and Solidago graminifolia) and quackgrass (Agropyron repens) but consists of more than 15 species of grasses and herbs. Vegetation biomass on the irrigated field peaked at 7880 kg/ha in mid-August in 1976.

GENERAL METHODS

Seasonal mass balances for water, chloride, nitrogen, and phosphorus were constructed. Such mass balances required hydrologic and water quality data on spray and precipitation input, surface runoff, infiltration, and

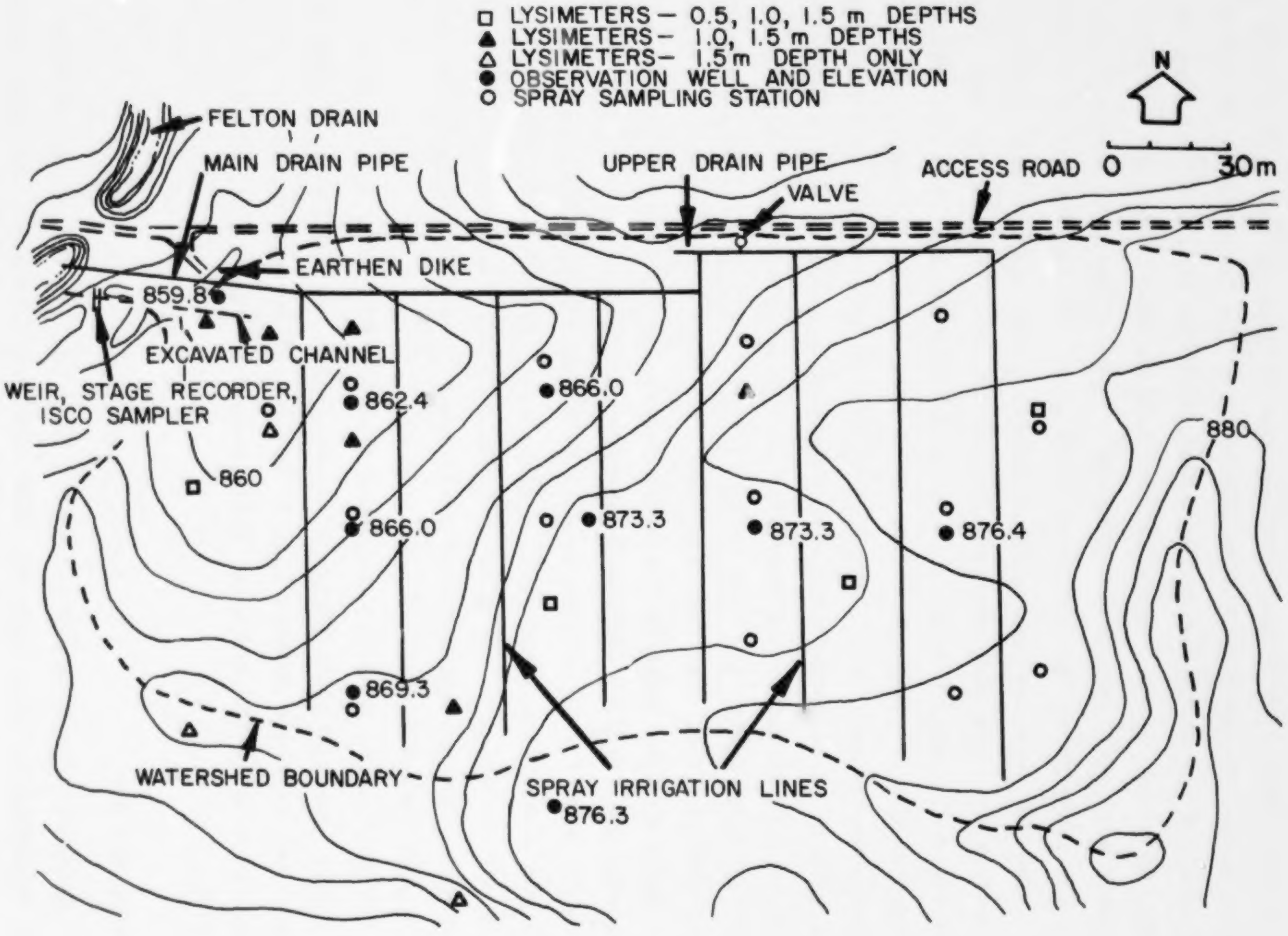
□ LYSIMETERS — 0.5, 1.0, 1.5 m DEPTHS
▲ LYSIMETERS — 1.0, 1.5 m DEPTHS
△ LYSIMETERS — 1.5 m DEPTH ONLY
● OBSERVATION WELL AND ELEVATION
○ SPRAY SAMPLING STATION
N
0
30m
FELTON DRAIN
MAIN DRAIN PIPE
UPPER DRAIN PIPE
VALVE
ACCESS ROAD
EARTHEN DIKE
859.8
EXCAVATED CHANNEL
WEIR, STAGE RECORDER, ISCO SAMPLER
862.4
860
866.0
866.0
873.3
873.3
876.4
880
869.3
WATERSHED BOUNDARY
SPRAY IRRIGATION LINES
876.3

Figure 8-1: Detail map of winter spray site.

evapotranspiration. Equipment locations are shown in Figure 8-1. Spray input volume was determined from WQMP pumping records and water quality samples of spray were collected at various locations in the field. Precipitation input was measured with a Bendix recording rain gauge located near the site. Precipitation quality was not measured; previously published values for mid-western locations were used: 0.027 mg P/ℓ total phosphorus, 0.35 mg Cl/ℓ chloride, 2.67 mg N/ℓ nitrate, 0.25 mg N/ℓ ammonia.[7,8] Surface runoff was conducted to Felton Drain by the excavated channel shown in Figure 8-1. Streamflow data and water quality samples were collected as shown in Figure 8-2. An ISCO model 1392 sequential sampler was used to accomplish detailed automatic surface runoff sampling. Samples of infiltrated water were collected in porous cup suction lysimeters at several depths in various locations around the spray site and the depth to the groundwater table was measured in shallow observation wells at locations shown in Figure 8-1. Evapotranspiration was estimated using the empirical method proposed by Thornthwaite which employs easily obtainable local weather data.[9]

Research at the Pennsylvania State University established that 5 cm (2 inches) per week was a safe secondary effluent application rate for perennial grasses.[2] In the current study 2.5 cm (1 inch) of wastewater was applied to the site twice per week at the rate of 0.84 cm/hr using Buckner 8600 agricultural spray heads spaced at 27.4 m (90 feet) intervals. No wastewater was applied during periods of surface runoff.

Water quality determinations were performed by the Institute of Water Research Water Quality Laboratory. The following analyses were performed according to U.S. Environmental Protection Agency approved autoanalyzer methods[10]: automated chloride method (Storet 00940), automated colorimetric phenate ammonia nitrogen method (Storet 00610), nitrite nitrogen (Storet 00615), automated cadmium reduction nitrate-nitrite nitrogen method (Storet 00630), and persulfate digestion total phosphorus method (Storet 00665).

COMPUTATIONAL METHODS

Determination of mass balances in this experiment required calculation of a number of input and output components. Nutrient and water inputs

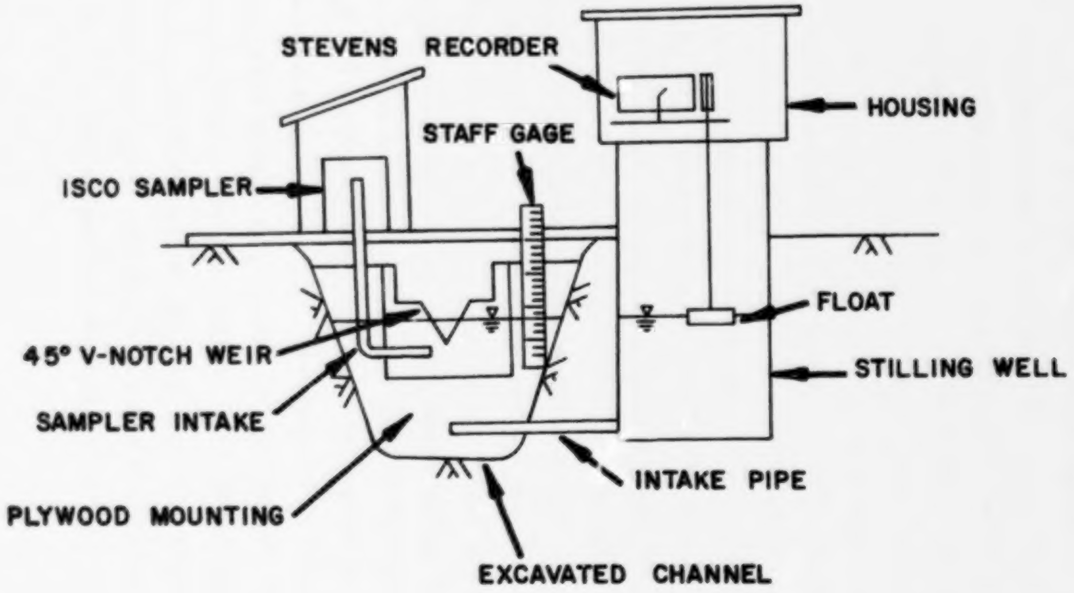
STEVENS RECORDER
HOUSING
STAFF GAGE
ISCO SAMPLER
FLOAT
45° V-NOTCH WEIR
STILLING WELL
SAMPLER INTAKE
INTAKE PIPE
PLYWOOD MOUNTING
EXCAVATED CHANNEL

Figure 8-2: Runoff monitoring station.

resulted from spray and precipitation. Nutrient and water outputs included infiltration, surface runoff, and the water and nutrient "loss" associated with evapotranspiration, soil nutrient removal and retention processes, and dilution in the groundwater. Data was analyzed on a seasonal basis with seasonal periods delineated according to the hydrologic response of the watershed.

Surface runoff data were analyzed by generating daily runoff volume and nutrient mass totals from stage-time and water quality-time data. Nutrient mass input from spray and precipitation volume and average quality were caluclated in a straightforward manner. Because of difficulties encountered in measuring infiltration under complex soil conditions, infiltration volume was estimated by subtracting surface runoff and evapotranspiration volumes from the total water input volumes.

Nutrient reduction in the soil was calculated assuming that the difference between the input nutrient mass, or applied nutrient mass, and the runoff nutrient mass gave the total nutrient mass infiltrating (M). A seasonal anticipated infiltrated water nutrient concentration (A) assuming no removal of nutrient was calculated using M and the infiltration water volume estimate (I) as follows:

$$A,\ (\mathrm{mg}/\ell) = \frac{M}{I} \qquad (1)$$

This ratio reflected dilution and concentration effects due to precipitation and evapotranspiration. Seasonal nutrient reduction percentage in the soil (R) was computed by comparing A to the measured average seasonal nutrient concentration, or maximum concentration when a significant increasing concentration trend was observed, measured in lysimeter samples collected at the 150 cm depth (B):

$$R,\ (\%) = \frac{(A - B)}{A} \times 100 \qquad (2)$$

Reduction was assumed to include the effect of lateral inflow-outflow of groundwater and dilution in groundwater as well as soil nutrient renovation and retention processes. Overall nutrient reduction mass was computed as follows:

$$\text{Overall Reduction, (kg)} = \frac{R \times M}{100} \qquad (3)$$

Nutrient infiltration mass, the nutrient mass penetrating the soil to the 1.5 m depth, was obtained by difference:

$$\text{Infiltration Mass, (kg)} = M - \text{Overall Reduction} \qquad (4)$$

Negative seasonal R values were occasionally obtained for chloride when the time lag associated with slow changes in groundwater quality resulted in carry-over of high groundwater chloride levels into a season with a lower chloride mass input. These negative R values were incorporated into the overall mass balances for the study period but were assumed to be zero for seasonal mass balances to avoid calculation of negative seasonal overall reductions. While this procedure introduced some numerical inaccuracy in the seasonal data, it allowed construction of approximate seasonal balances to characterize the response of the site during different times of the year. Except when negative R values occur, it can be shown that:

$$\text{Infiltration Nutrient Mass, (kg)} = B \times I \qquad (5)$$

OVERALL RESULTS FOR STUDY PERIOD

The spray site was irrigated at a rate of 5 cm (2 inches) per week from December 1, 1975, to March 16, 1977, except during periods of spring runoff. Winter study periods included spring ice melt runoff events.

The overall water balance for the study period indicates that most of the output water from the site infiltrated with the remainder divided about equally between runoff and evapotranspiration as shown in TABLE 8-1. TABLE 8-2 lists runoff, evapotranspiration, and infiltration as a percent of total water input by season. Minimum runoff occurred during the summer and fall and maximum runoff occurred during the winter seasons. Infiltration was high during all seasons but was maximum during the fall and winter. Evapotranspiration was maximum during the summer growing season.

Overall mass balances are given in TABLE 8-3. Very small percentages of the input nitrogen and phosphorus accompanied the surface runoff; most of the nutrient input mass was taken up by the soil-plant system or diluted in the groundwater. Very little infiltrated phosphorus was detected at a depth of 1.5 m in the soil. Most of the input chloride infiltrated with little overall reduction taking place. TABLE 8-4 gives nutrient reduction

TABLE 8-1. OVERALL WATER BALANCE FOR STUDY PERIOD DECEMBER 1, 1975 TO MARCH 16, 1977

Source	Volume (m^3)	Percent of Total
Input		
Wastewater Spray	47,398	68
Precipitation	22,300	32
	69,698	100
Output		
Runoff	9,714	14
Infiltration	46,915	67
Evapotranspiration	13,069	19
	69,698	100

TABLE 8-2. RUNOFF, INFILTRATION, AND EVAPOTRANSPIRATION AS PERCENT OF TOTAL WATER INPUT BY SEASON

Season	Runoff, % Input	Infiltration % Input	Evapotranspiration, % Input
Winter 1976 12/1/75-2/27/76	27	73	~0
Spring 1976 2/28/76-5/27/76	23	57	20
Summer 1976 5/28/76-8/31/76	0	57	43
Fall 1976 9/1/76-11/30/76	4	83	13
Winter 1977 12/1/76-3/16/77	29	71	~0

TABLE 8-3. OVERALL NUTRIENT MASS BALANCES FOR STUDY PERIOD DECEMBER 1, 1975 TO MARCH 16, 1977

Nutrient	Input kg		Runoff		Overall Reduction		Infiltration	
	spray	rain	kg	% of input	kg	% of input	kg	% of input
Chloride (as Cl)	5,868	8	680	12	109	2	5,087	86
Nitrate (as N)	519	59	24	4	491	85	63	11
Ammonia (as N)	41	6	1	2	36	77	10	21
Total Phosphorus (as P)	163	0.6	6	4	149	91	8.6	5

TABLE 8-4. NUTRIENT REDUCTION IN THE SOIL BY SEASON

Season	Percent Reduction in the Soil, (R)			
	Chloride	Ammonia	Nitrate	Total Phosphorus
Winter 1976 12/1/75-2/27/76	17	75	93	99
Spring 1976 2/28/76-5/27/76	-54	60	98	98
Summer 1976 5/28/76-8/31/76	39	91	99	99
Fall 1976 9/1/76-11/30/76	-20	66	99	99
Winter 1977 12/1/76-3/16/77	-28	60	68	85

(R) in the soil by season. Reduction was high during all seasons with the lowest values during the winter of 1977. The ammonia reduction estimate was unreliable due to the small input mass.

Nitrogen to chloride ratios for groundwater and applied wastewater were calculated and are given in Figure 8-3. Lake renovated effluent was applied from January to April, 1976. Direct secondary effluent containing higher nitrogen levels was applied from May, 1976, to February, 1977. Nitrogen in the applied wastewater was primarily in the nitrate form and chloride levels were fairly uniform throughout the study period. These ratios indicate a high degree of nitrogen interception during the summer and fall and marked breakthrough of nitrogen to the groundwater during the winter 1977 season.

WINTER 1977 RESULTS

The winter, 1977 was a record period of severe cold weather with little snowfall. From December 1, 1976, to February 22, 1977, 46 cm (18 inches) of direct secondary effluent were applied to the site resulting in heavy ice buildup. Frozen pipes and valves resulted in operational shutdown several times; spray distribution was uneven due to spray nozzle freeze-up. Average wastewater input nutrient concentrations were the highest of the study period: 127 mg Cl/ℓ chloride, 18.4 mg N/ℓ nitrate, 5.6 mg P/ℓ total phosphorus, and 0.5 mg N/ℓ ammonia. Nitrite concentrations were less than 0.1 mg N/ℓ. Spring thaw brought considerable runoff from ice melt and rainfall during February and March, and runoff ceased on March 16 marking the end of the winter study period.

TABLE 8-5 gives the water balance for the winter period. Most of the input water was wastewater; little precipitation was recorded. Subfreezing temperatures resulted in an evapotranspiration estimate of zero. Field observations revealed unfrozen conditions under the ice pack apparently due to the ice pack insulating the soil against frost penetration; as a result most of the output water infiltrated.

The winter nutrient mass balances are given in TABLE 8-6. The nitrite balance was not significant due to low input levels. The lowest overall reductions of nitrate and phosphorus observed during the study period

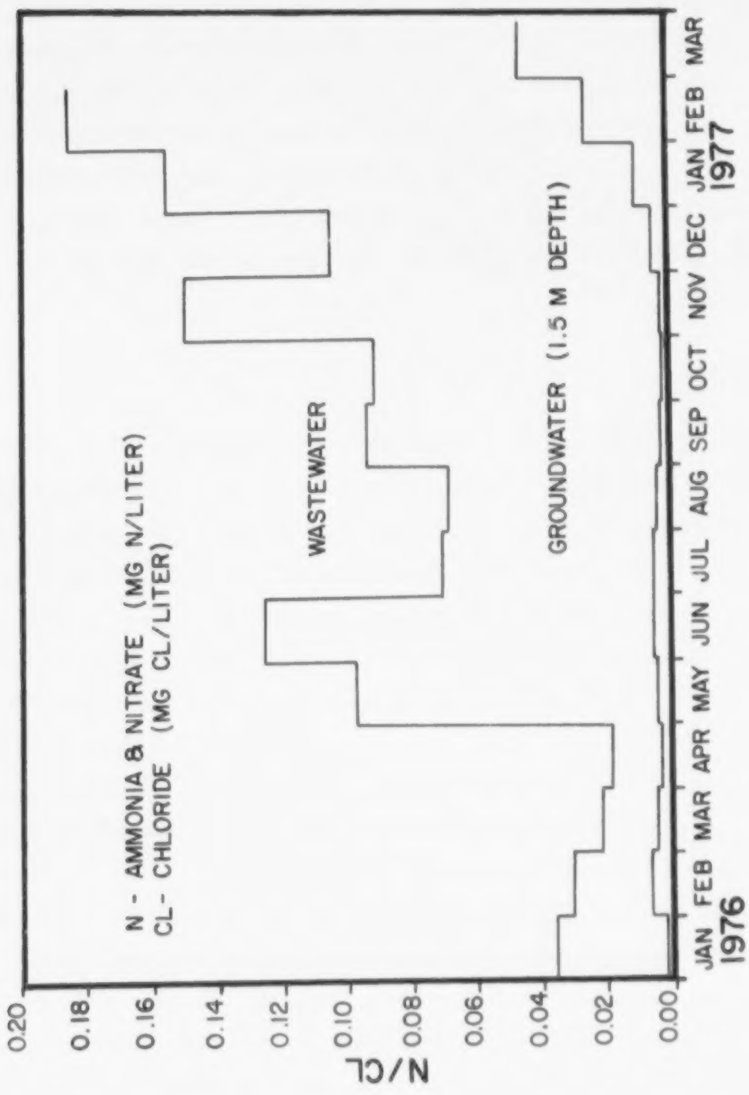

Figure 8-3: Monthly nitrogen to chloride ratios.

TABLE 8-5. WATER BALANCES - WINTER 1977, DECEMBER 1, 1976 TO MARCH 16, 1977

Source	Volume m^3	Percent of Total
Input		
Spray	10,646	84
Precipitation	1,994	16
	12,640	100
Output		
Runoff	3,700	29
Infiltration	8,940	71
Evapotranspiration	0	0
	12,640	100

TABLE 8-6. NUTRIENT BALANCE - WINTER 1977, DECEMBER 1, 1976 TO MARCH 16, 1977.

Nutrient	Input kg		Runoff		Overall Reduction		Infiltration	
	spray	rain	kg	% of Input	kg	% of Input	kg	% of Input
Chloride (as Cl)	1,349	1	287	21	0	0	1,063	79
Nitrate (as N)	196	5	23	11	121	61	57	28
Ammonia (as N)	5.5	0.5	1.1	18	2.9	49	2.0	33
Total Phosphorus (as P)	60	0.1	6	10	46.0	77	8.1	13

occurred. Higher percentages of nutrient input mass accompanied the runoff than in previous seasons.

Figure 8-4 gives lysimeter nitrate data for the winter period. Severe cold caused many of the lysimeter access tubes to freeze and few samples were collected until after the thaw in March. Sufficient samples were collected to show the effect of irrigation on the groundwater at the site. Prior to saturation of the site by spring ice melt, several average nitrate peaks greater than 10 mg N/ℓ were observed at the 1 meter (3 ft.) depth. The average nitrate concentration at the 1.5 meter (5 ft.) depth reached about 6 mg N/ℓ in spite of groundwater dilution.

Average daily discharge and nutrient concentrations during the spring runoff period are shown in Figure 8-5. Initial runoff nutrient concentrations were considerably higher than input levels, probably due to freeze-out of pure water. Concentrations decreased steadily but phosphorus levels remained above 1.0 mg P/ℓ during most of the runoff period.

Nutrient mass flow rates are plotted with a typical winter hydrograph in Figure 8-6. Mass flow rates varied with discharge and peak mass flow rates occurred with peak discharge. This behavior was also common during other seasons.

Soil water and runoff water quality during the winter 1977 period were the poorest of the study period. Significant nitrate buildup was observed in the groundwater, but nitrate levels remained below 10 mg N/ℓ probably due to dilution. In terms of total mass applied, 90% of the input phosphorus was retained on the site; however, the Michigan phosphorus discharge standard was violated during most of the spring runoff period. Runoff volume was small allowing most of the input water to infiltrate causing greatly increased water table elevations and saturation of most of the site.

CONCLUSIONS AND APPLICATION

From the results of this study, a number of conclusions can be drawn concerning the impact of secondary municipal sewage effluent irrigation on an unmodified natural watershed during northern winters. Frost penetration into the soil was apparently prevented by beginning irrigation early in the winter season which subsequently built up a protective ice pack. This procedure allowed significant infiltration from ice melt at the ground surface

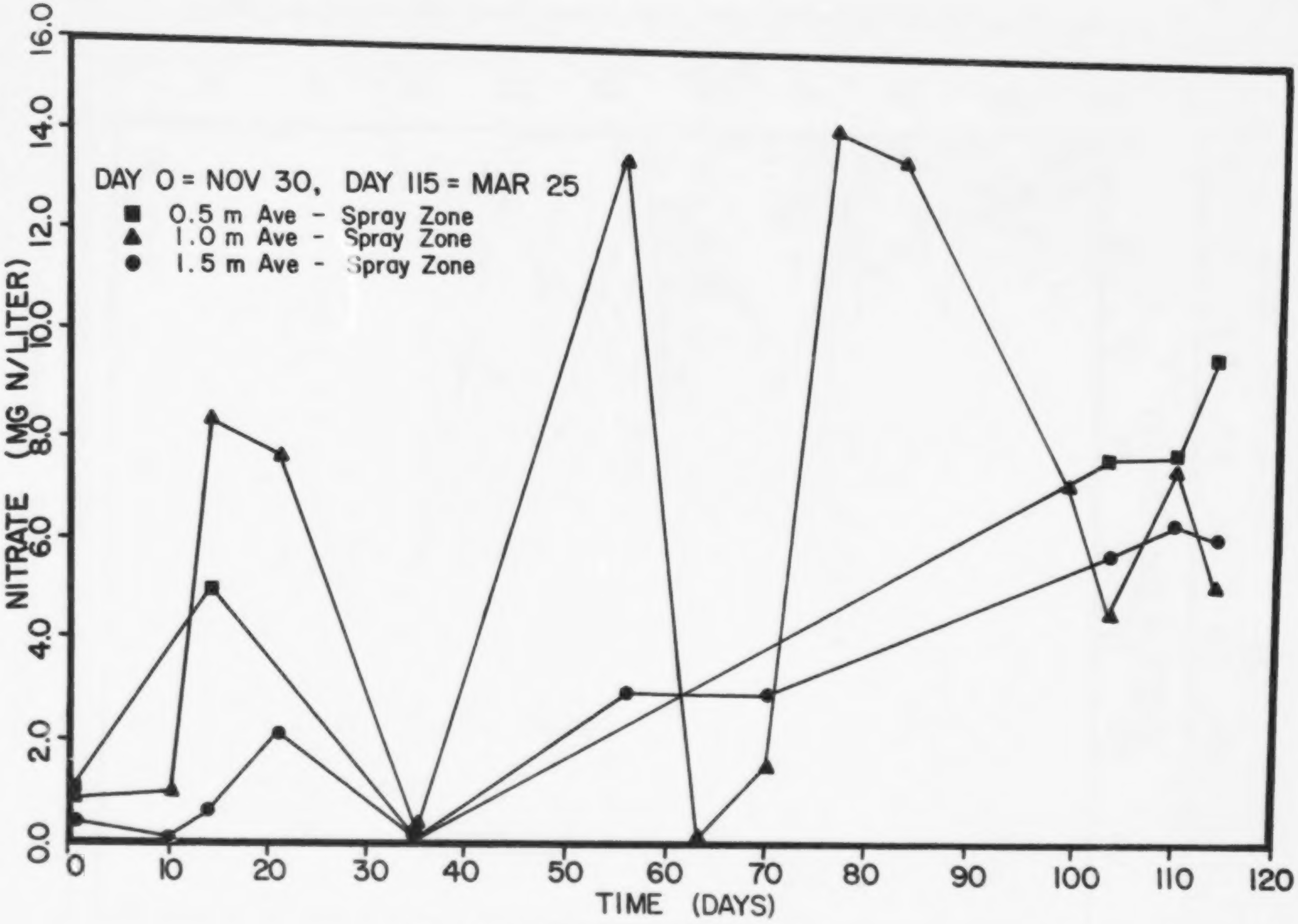

Figure 8-4: Winter 1977 lysimeter data.

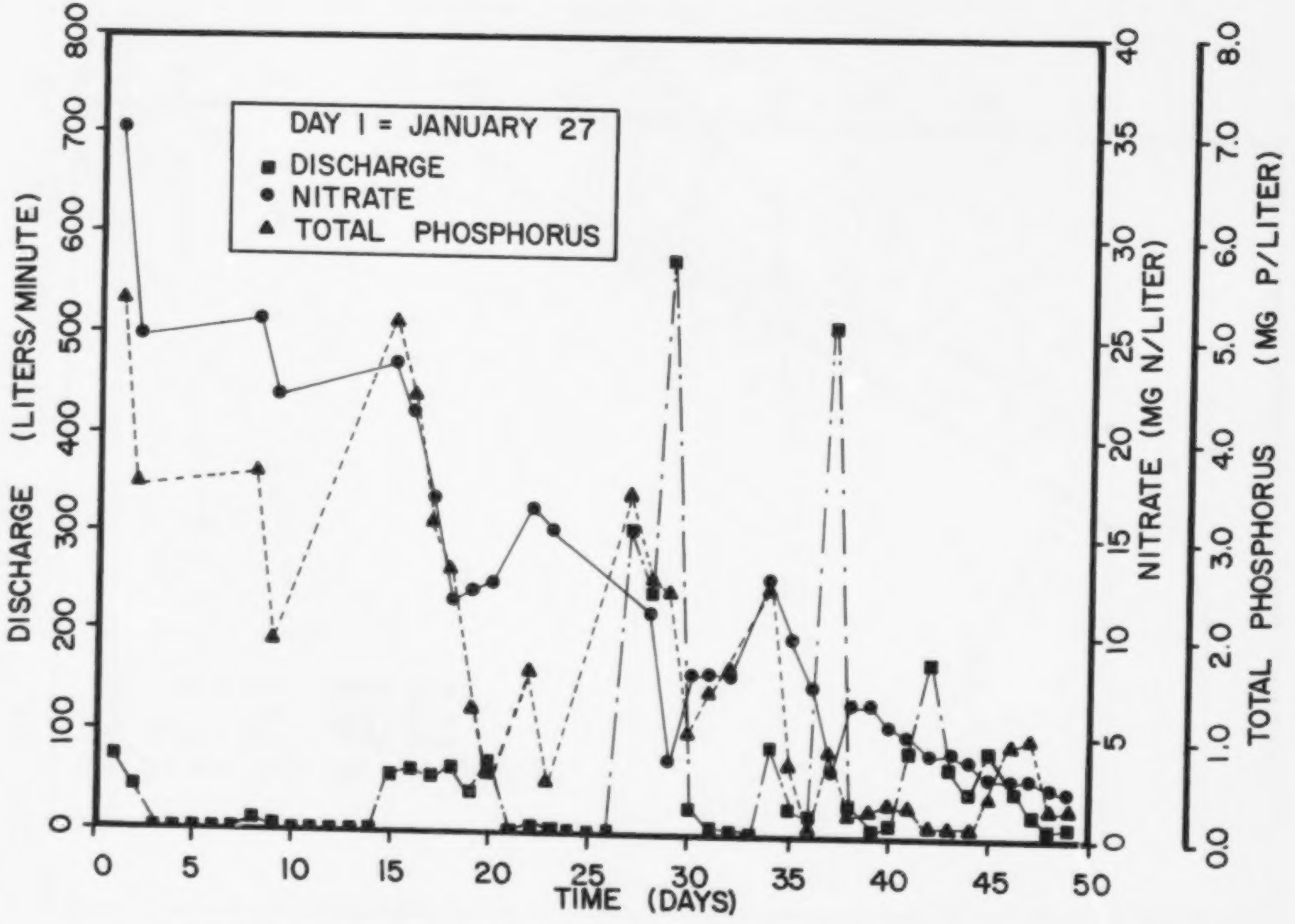

Figure 8-5: Average daily runoff water quality and discharge, Winter 1977.

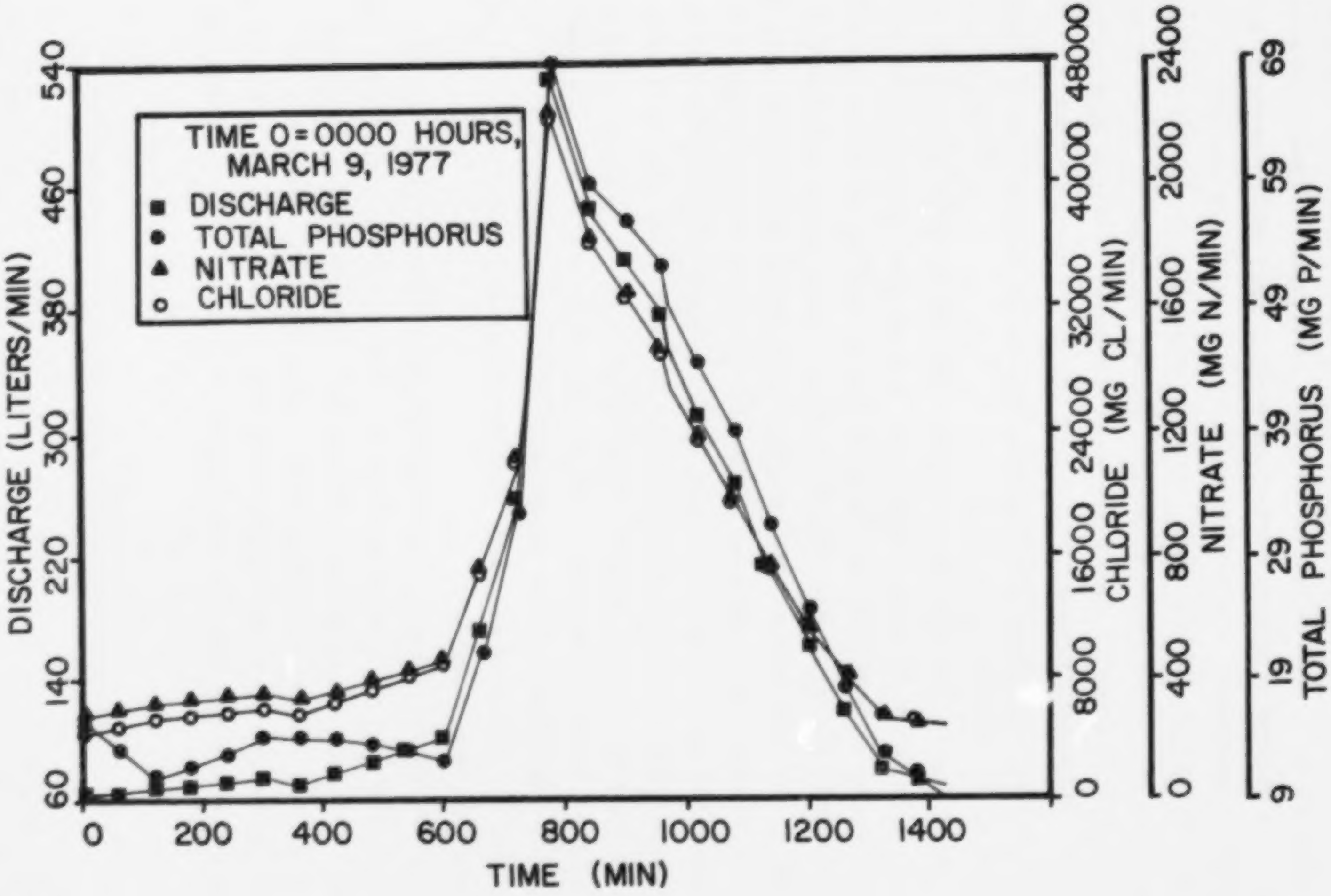

Figure 8-6. Hydrograph and nutrient mass flows, March 9, 1977.

to occur throughout the winter on a site which had good infiltration characteristics, and runoff volume was reduced as a result. Site saturation evident at the end of winter operations could impair spring irrigation operations. Groundwater and runoff quality was poor during the winter periods compared to the rest of the year. Nitrate accumulation accurred in the groundwater and levels could ultimately exceed the standard of 10 mg N/ℓ, although they did not in this experiment. In terms of total mass applied, effective phosphorus renovation occurred during winter operations but high concentrations in surface runoff during the spring violated the discharge standard of 1.0 mg P/ℓ.

Irrigation during the winter months with low nitrogen wastewater is an obvious solution to the nitrogen infiltration problem. This low nitrogen wastewater is available in the WQMP lake system in the late fall as a result of lake mediated nitrogen stripping processes, and irrigation from the end of the lake system could continue into the winter months while new effluent is taken in at the head of the lake system. Winter irrigation for phosphorus removal could proceed until the lake effluent nitrogen concentration reaches 10 mg N/ℓ, effectively increasing the operating season of the system by several months. Phosphorus retention could be enhanced by diking or contour plowing to increase soil contact. Winter wastewater irrigation can therefore be a potentially viable management option for operation of a combined land-lake tertiary treatment system for nitrogen and phosphorus renovation.

Further investigations should be carried out before this type of system is operated on a year-round basis. The fate of bacteria and viruses during winter operation should be determined. The wastewater employed in this study was exclusively domestic municipal effluent, therefore the effects of heavy metals and industrial wastes during winter operations should be determined before these findings are extended to such systems.

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SECTION 9

BASELINE OLDFIELD WATERSHED STUDIES

Thomas M. Burton and James E. Hook

INTRODUCTION

According to preliminary estimates of PLUARG, 33% of the total land area of the Great Lakes Basin is in agricultural usage. Of this agricultural land, approximately 56% or 103,600 km^2 are in low intensity agricultural uses such as pasture or range land. Thus, it is essential that runoff from such low intensity land uses be quantified so that the total contribution of these lands to non-point source pollution of the Great Lakes can be estimated. An unknown but probably substantial amount of the low intensity "agricultural" land represents marginal farm lands that have been abandoned and are now in successional, oldfield vegetation. Runoff from such cleared, unproductive lands should contain nitrogen and phosphorus concentrations higher than runoff from forested lands but lower than runoff from intensive agricultural or urban watersheds because of the residual effect of past agricultural practices.[1] The recent nationwide survey of stream nutrient levels in relation to land use did include such cleared unproductive lands but the relatively few watersheds in this survey allowed only limited interpretation.[1] Nutrient losses in surface runoff from native prairie in west central Minnesota have been intensively studied,[2] but nutrient losses from successional oldfield watersheds in the Great Lakes Basin have received little attention. Thus, a study of runoff losses from an abandoned farm field was included as part of the Felton-Herron Creek Pilot Watershed Study. The objective of this study was to quantify losses of nitrogen, phosphorus, and other nutrients from abandoned farm lands in lower Michigan.

MATERIALS AND METHODS

An oldfield that had been abandoned approximately 18 years ago was selected for study. The predominant vegetation on this field was goldenrod (*Solidago sp.*) and quackgrass (*Agropyron repens*), but a very diverse flora existed. Most of this field was included in a 7.73 ha subwatershed with well delineated topographic boundaries on the Water Quality Management Project's land irrigation site. Furthermore, an existing drainage tile installed while the field was in cultivation was still functional and provided a convenient place to sample runoff from this subwatershed. The drainage tile emptied into an artificial channel at the edge of the field. Discharge from this channel was measured with a V-notch weir and a Stevens Type F recorder. Water samples were taken during spring runoff and storm events with an ISCO sequential water sampler. These samples were supplemented by low flow grab samples.

All samples were analyzed following standard techniques established for IJC studies. Analyses included total P, molybdate reactive P, NO_3-N, NO_2-N, NH_4-N, total Kjeldahl N (includes NH_4-N), Cl, suspended solids, sodium, and calcium.

Porous cup tube-type vacuum lysimeters were also installed at 15, 30, 60, 90, 120, and 150 cm depths at 10 sites throughout the watershed. Soil-water samples from these lysimeters were taken weekly throughout the growing seasons of 1976 and 1977 and occasionally through the winter of 1976, and analyzed for all forms of N, P, and Cl.

Soil samples were taken in increments to a depth of 150 cm and analyzed for Bray extractable P, NO_3-N, Cl, Ca, Mg, Na, and K in 1975 and in 1976. The 1975 samples were taken to a depth of 300 cm and were also analyzed for total P and Kjeldahl N. All analyses followed standard techniques or modifications described in Section 5.[3] Single soil samples were taken at the 10 lysimeter sites in 1976. Paired soil samples were taken in 1975 at 24 sites along a "star" shaped group of criss-crossing transects.

Precipitation inputs were monitored with three recording rain gauges at nearby localities.

The soils have been mapped (see map in Section 4) and are predominantly loam or sandy loams. There apparently is a fairly continuous clay lens underlying the lower central portion of this watershed, since relatively impermeable reduced clays were encountered at every soil sampling site in the lower central part of the watershed. The existence of this clay lens results in a perched shallow water table. As a result, samples of soil-water were taken in these areas with suction lysimeters even after mid-summer drought conditions when the adjacent non-irrigated forest and oldfield areas described in Sections 5 and 7 were too dry for sampling.

RESULTS AND DISCUSSION

The water budgets for the baseline watershed indicated that little, if any, recharge of groundwater occurred (TABLE 9-1). Almost all excess water appears to have been intercepted by the existing tile drainage system and exported from the watershed as runoff. The excessive runoff from this site compared to nearby unirrigated forest and oldfield sites (Sections 5 and 7) probably resulted from the clay lens underlying the lower central portion of this watershed as discussed earlier as well as the existing tile drain. Tile drainage systems have been shown to be inefficient at intercepting all water available for runoff or recharge in this area, at least under irrigated conditions at a nearby site.[4] Thus, soil-water samples obtained at the 15 and 150 cm depths with porous cup lysimeters were useful in characterizing storage of nutrients in the soil-water reservoir but not as a means of characterizing water quality of groundwater leachates. Consequently, most emphasis in this discussion will be on runoff of nutrients from the site.

Soil-Water Analyses

Soil-water analyses, however, do indicate the very infertile nature of this abandoned farm field. For example, nitrate-N increased to a yearly high of 0.55 ± .52 mg N/ℓ at the 15 cm depth on March 24, 1977 after the soil began to warm, decreased rapidly to less than 0.01 mg N/ℓ by April 28, 1977, then increased slightly by mid-May with the weekly average varying from 0.01 to 0.11 throughout the rest of the summer and fall. Nitrate-N concentrations at the 150 cm depth were similar and varied from a seasonal high of 0.30 ± .16 mg N/ℓ on April 7, 1977 down to a low of 0.06 ± .02 mg

TABLE 9-1. WATER BUDGETS FOR THE OLDFIELD BASELINE WATERSHED (VALUES IN m^3/ha)

Month	Precipitation	Evapotranspiration	Runoff	Recharge
October 1975	215.9	315.9	0	-100.0
November 1975	613.0	244.5	32.3	336.2
December 1975	734.1	0	231.6	502.5
January 1976	307.3	0	137.4	169.9
February 1976	520.7	0	541.9	-21.2
March 1976	1027.9	153.8	657.8	216.3
April 1976	996.5	436.8	418.0	141.7
May 1976	614.7	718.2	284.7	-388.2
June 1976	1112.5	1262.5	45.2	-195.2
July 1976	657.0	1187.0	29.2	-559.2
August 1976	135.5	695.5	0	-560.0
September 1976	394.5	534.5	0	-140.0
ANNUAL	7329.6	5548.7	2378.1	-597.2
% of Input	100.0	75.7	32.45	-8.15
October 1976	520.7	285.0	0	235.7
November 1976	201.9	0	0	201.9
December 1976	129.5	0	0	129.5
January 1977	96.5	0	0	96.5
February 1977	159.2	0	21.7	137.5
March 1977	701.0	184.5	108.0	408.5
April 1977	1027.9	504.0	323.0	200.9
May 1977	124.5	934.5	14.1	-824.1
June 1977	1030.4	1050.4	0.8	-20.8
July 1977	422.0	1022.0	0	-580.0
August 1977	607.1	827.1	0	-220.0
September 1977	1148.1	811.2	0	336.9
ANNUAL	6188.8	5618.7	467.6	102.5
% of Input	100.0	90.79	7.56	1.66

N/ℓ in August. Weekly average concentrations varied between 0.06 and 0.13 mg N/ℓ throughout most of the summer and fall. Spring peaks of nitrate-N are the norm in fallow soils.[5] Ammonia-N levels were also very low in soil-water with weekly averages varying between 0.02 and 0.25 mg N/ℓ at the 15 cm depth and between 0.05 and 0.27 mg N/ℓ at the 150 cm depth. Nitrite-N was always below limits of detection (0.01 mg N/ℓ). Weekly average organic-N concentrations varied from 0.34 to 0.93 mg N/ℓ at the 15 cm depth and from 0.08 to 0.82 mg N/ℓ at the 150 cm depth with no obvious seasonal correlation.

Total P concentrations in soil-water were also very low with the weekly average varying from 0.02 to 0.36 mg P/ℓ at the 15 cm depth and from 0.003 to 0.32 mg P/ℓ at the 150 cm depth. Most weekly averages were less than 0.080 mg P/ℓ at both depths. There were no obvious seasonal trends.

Chloride concentrations were also low with weekly averages varying from 1.4 to 8.4 mg Cl/ℓ with no obvious seasonal differences. There may have been a slight increase with depth with the 150 cm depth often being slightly higher than the 15 cm depth on any given week. The weekly average varied between 1.8 and 7.7 mg Cl/ℓ for the 150 cm depth.

Runoff

Seasonal and annual runoff loadings are presented in TABLES 9-2 to 9-6. Chloride concentrations rose substantially during spring runoff in 1977 indicating some contamination from a nearby spray irrigation project. Also, the lysimeter site located near the runoff monitoring station showed chloride contamination at the 150 cm depth during the spring of 1977. No other lysimeter site had chloride contamination problems, so contamination affected only a small area of the baseline watershed. Nevertheless, loadings from only the 1975-76 water year should be used because of this contamination problem, and no 1977 runoff data are presented (TABLES 9-2 to 9-6).

The annual flow weighted mean concentration of 0.073 mg total P/ℓ is low compared to the 0.152 mg total P/ℓ reported for intense agricultural land for this region.[1] It is intermediate between values reported for agricultural and forest land uses as was predicted by Omernik.[1] Orthophosphorus concentrations (0.028 mg P/ℓ) also are intermediate between forest and agricultural land uses as was predicted. However, both total and inorganic nitrogen concentrations fall in the range (0.047 NO_3-N, 0.078 NH_4-N, 0.017 NO_2-N) reported for forested land.[1] Concentrations of P reported here agree well with those estimates derived by Omernik[1] for the eastern region (which included the Great Lakes Basin) of the United States for land in the 50% agriculture plus urban land use category. Total N concentrations (0.561 mg N/ℓ) are nearer those reported for the 0% agricultural plus urban land use category.[1]

TABLE 9-2. STREAM EXPORT OF MOLYBDATE REACTIVE PHOSPHORUS AND TOTAL PHOSPHORUS FROM THE 7.73 ha BASELINE OLDFIELD WATERSHED

Season	---------- EVENT FLOWS -------- Rising Hydrograph (kg)	Descending Hydrograph (kg)	Non-Event Flows (kg)	Total Exports (kg)	% of Total	Unit Area Load (kg/ha)
MOLYBDATE REACTIVE PHOSPHORUS						
Fall, 1975	0.014 ± .0001	0.059 ± .001	0.006 ± 0.000	0.079 ± .001	9.54	0.010
Winter, 1975-76	0.004 ± .0001	0.025 ± .0004	0.042 ± 0.398	0.071 ± .398	8.57	0.009
Spring Runoff 1976	0.079 ± .002	0.204 ± .022	0.029 ± 0.065	0.312 ± .069	37.68	0.040
Spring Post Runoff '76	0.074 ± .001	0.164 ± .046	0.041 ± 0.283	0.279 ± .287	33.70	0.036
Summer, 1976	0.035 ± .001	0.051 ± .002	0.0008 ± 0.001	0.087 ± .002	10.51	0.011
Total 75-76 Water Year	0.206 ± .002	0.503 ± .051	0.119 ± 0.493	0.828 ± .496		0.107
% of Total	24.88	60.75	14.37			
Fall, 1976	0	0	0	0	---	0
Winter, 1976-77	0	0	0	0	---	0
Spring Runoff 1977	0.008 ± .0001	0.083 ± .001	0.020 ± 0.013	0.111 ± .013	---	0.002
TOTAL PHOSPHORUS						
Fall, 1975	0.017 ± .00004	0.062 ± .001	0.007 ± .008	0.086 ± .008	3.67	0.011
Winter, 1975-76	0.012 ± .0002	0.037 ± .0004	0.170 ± .789	0.219 ± .789	9.35	0.028
Spring Runoff 1976	0.416 ± .008	0.535 ± .032	0.106 ± .203	1.057 ± .206	45.11	0.137
Spring Post Runoff '76	0.205 ± .004	0.445 ± .067	0.088 ± .450	0.738 ± .455	31.50	0.096
Summer, 1976	0.112 ± .001	0.129 ± .004	0.002 ± .002	0.243 ± .005	10.37	0.031
Total 75-76 Water Year	0.762 ± .009	1.208 ± .074	0.373 ± .931	2.343 ± .934		0.303
% of Total	32.52	51.56	15.92			
Fall, 1976	0	0	0	0	---	0
Winter, 1976-77	0	0	0	0	---	0
Spring Runoff 1977	0.019 ± .0002	0.235 ± .008	0.109 ± .263	0.363 ± .263	---	0.047

TABLE 9-3. STREAM EXPORT OF NITRATE AND AMMONIA NITROGEN FROM THE 7.73 ha BASELINE OLDFIELD WATERSHED

Season	-------- EVENT FLOWS ---------					
	Rising Hydrograph (kg)	Descending Hydrograph (kg)	Non-Event Flows (kg)	Total Exports (kg)	% of Total	Unit Area Load (kg/ha)
			N I T R A T E - N I T R O G E N			
Fall, 1975	0.020 ± .0001	0.095 ± .001	0.024 ± .084	0.139 ± .084	10.30	0.018
Winter, 1975-76	0.016 ± .0002	0.023 ± .0004	0.185 ± .259	0.224 ± .259	16.59	0.029
Spring Runoff 1976	0.182 ± .002	0.399 ± .018	0.062 ± .102	0.643 ± .104	47.63	0.083
Spring Post Runoff '76	0.026 ± .0004	0.181 ± .004	0.031 ± .037	0.238 ± .037	17.63	0.031
Summer, 1976	0.018 ± .0002	0.077 ± .002	0.011 ± .003	0.106 ± .004	7.85	0.014
Total 75-76 Water Year	0.262 ± .002	0.775 ± .019	0.313 ± .293	1.350 ± .294		0.175
% of Total	19.41	57.41	23.19			
Fall, 1976	0	0	0	0	---	0
Winter, 1976-77	0	0	0	0	---	0
Spring Runoff 1977	0.097 ± .001	0.302 ± .005	0.349 ± .103	0.748 ± .103	---	0.097
			A M M O N I A - N I T R O G E N			
Fall, 1975	0.001 ± .00001	0.011 ± .0002	0.001 ± 0.042	0.013 ± 0.042	0.53	0.002
Winter, 1975-76	0.016 ± .0004	0.015 ± .0002	0.115 ± 1.941	0.146 ± 1.941	5.91	0.019
Spring Runoff 1976	0.113 ± .002	0.463 ± .036	0.090 ± 0.262	0.666 ± 0.264	26.95	0.086
Spring Post Runoff '76	0.659 ± .039	0.711 ± .050	0.218 ± 1.239	1.588 ± 1.241	64.27	0.205
Summer, 1976	0.020 ± .0002	0.036 ± .0004	0.002 ± 0.004	0.058 ± 0.004	2.35	0.008
Total 75-76 Water Year	0.809 ± .039	1.236 ± .062	0.426 ± 2.318	2.471 ± 2.319		0.320
% of Total	32.74	50.02	17.24			
Fall, 1976	0	0	0	0	---	0
Winter, 1976-77	0	0	0	0	---	0
Spring Runoff 1977	0.009 ± .0001	0.117 ± .001	0.057 ± 0.059	0.183 ± 0.059	---	0.024

TABLE 9-4. STREAM EXPORT OF NITRITE AND TOTAL KJELDAHL NITROGEN FROM THE 7.73 ha BASELINE OLDFIELD WATERSHED

	EVENT FLOWS					
Season	Rising Hydrograph (kg)	Descending Hydrograph (kg)	Non-Event Flows (kg)	Total Exports (kg)	% of Total	Unit Area Load (kg/ha)
			NITRITE-NITROGEN			
Fall, 1975	ND[#]	ND	ND	ND	*	ND
Winter, 1975-76	0.001 ± .00002	0.004 ± 0.0001	0.015 ± 0.033	0.020 ± .033	5.09	0.003
Spring Runoff 1976	0.021 ± .0003	0.176 ± 0.033	0.019 ± 0.030	0.216 ± .045	54.96	0.028
Spring Post Runoff '76	0.084 ± .003	0.054 ± 0.005	0.011 ± 0.019	0.149 ± .020	37.91	0.019
Summer, 1976	0.004 ± .00004	0.004 ± 0.000	0.0004 ± 0.000	0.008 ± .00004	2.04	0.001
Total 75-76 Water Year*	0.110 ± .003	0.238 ± 0.033	0.045 ± 0.048	0.393 ± .059		0.051
% of Total	27.99	60.56	11.45			
Fall, 1976	0	0	0	0	0	0
Winter, 1976-77	0	0	0	0	0	0
Spring Runoff 1977	0.006 ± .0001	0.021 ± 0.001	0.013 ± 0.011	0.040 ± .011	---	0.005
			TOTAL KJELDAHL-NITROGEN			
Fall, 1975	0.122 ± .0004	0.420 ± .002	0.081 ± 0.418	0.623 ± 0.418	3.84	0.081
Winter, 1975-76	0.069 ± .001	0.083 ± .001	0.835 ± 4.457	0.987 ± 4.457	6.08	0.128
Spring Runoff 1976	1.589 ± .037	3.863 ± .123	0.961 ± 1.078	6.413 ± 1.086	39.50	0.830
Spring Post Runoff '76	1.334 ± .021	4.949 ± .717	0.846 ± 1.153	7.129 ± 1.358	43.91	0.922
Summer, 1976	0.362 ± .003	0.672 ± .003	0.048 ± 0.005	1.082 ± 0.006	6.67	0.140
Total 75-76 Water Year*	3.476 ± .043	9.987 ± .728	2.771 ± 4.747	16.234 ± 4.802		2.100
% of Total	21.41	61.52	17.07			
Fall, 1976	0	0	0	0	0	0
Winter, 1976-77	0	0	0	0	0	0
Spring Runoff 1977	0.144 ± .001	1.269 ± .036	0.936 ± 0.425	2.349 ± 0.427	---	0.304

[#] ND indicates no data.

* 1975-76 water year data for NO_2-N were calculated using Fall, 1976, data since no Fall, 1975, data were collected.

TABLE 9-5. STREAM EXPORT OF CHLORIDE AND SUSPENDED SOLIDS FROM THE 7.73 ha BASELINE OLDFIELD WATERSHED

Season	EVENT FLOWS Rising Hydrograph (kg)	EVENT FLOWS Descending Hydrograph (kg)	Non-Event Flows (kg)	Total Exports (kg)	% of Total	Unit Area Load (kg/ha)
		CHLORIDE				
Fall, 1975	1.52 ± 0.01	17.78 ± 0.10	6.76 ± 8.37	26.06 ± 8.37	5.34	3.37
Winter, 1975-76	12.70 ± 0.16	17.45 ± 0.08	117.58 ± 254.41	147.73 ± 254.41	30.25	19.11
Spring Runoff 1976	20.07 ± 0.54	94.06 ± 3.54	71.92 ± 22.65	186.05 ± 22.93	38.10	24.07
Spring Post Runoff '76	11.49 ± 0.11	80.44 ± 1.45	31.30 ± 16.00	123.23 ± 16.07	25.23	15.94
Summer, 1976	0.96 ± 0.01	2.40 ± 0.014	1.90 ± 0.20	5.26 ± 0.20	1.08	0.68
Total 75-76 Water Year#	46.76 ± 0.57	212.13 ± 3.83	229.46 ± 256.05	488.35 ± 256.08		63.18
% of Total	9.58	43.44	46.99			
Fall, 1976	0	0	0	0	0	0
Winter, 1976-77	0	0	0	0	0	0
Spring Runoff 1977*	6.90 ± 0.00	49.99 ± 0.45	113.52 ± 26.44	170.41 ± 26.44	----	22.04
		SUSPENDED SOLIDS				
Fall, 1975	ND**	ND	ND	ND	#	ND
Winter, 1975-76	0.84 ± 0.03	0.75 ± 0.09	21.00 ± 194.17	22.59 ± 194.17	7.35	2.92
Spring Runoff 1976	32.03 ± 0.87	31.40 ± 22.39	14.24 ± 34.87	77.67 ± 41.45	25.26	10.05
Spring Post Runoff '76	37.16 ± 3.82	98.08 ± 44.02	29.79 ± 153.53	165.03 ± 159.76	53.68	21.35
Summer, 1976	13.88 ± 0.0001	27.39 ± 2.15	0.87 ± 0.36	42.14 ± 2.18	13.71	5.45
Total 75-76 Water Year#	83.91 ± 3.92	157.62 ± 49.43	65.90 ± 249.98	307.43 ± 254.85		39.77
% of Total	27.29	51.27	21.44			
Fall, 1976	0	0	0	0	0	0
Winter, 1976-77	0	0	0	0	0	0
Spring Runoff 1977*	3.08 ± 0.25	13.07 ± 0.95	11.90 ± 16.69	28.05 ± 16.72	----	3.63

1975-76 water year data for suspended solids were calculated using Fall, 1976 data since no Fall, 1975 data were collected.

* Some Chloride contamination from an adjacent wastewater irrigation site during Spring runoff, 1977 but not at any other season.

** ND indicates no data.

TABLE 9-6. STREAM EXPORT OF SODIUM AND CALCIUM FROM THE 7.73 ha BASELINE OLDFIELD WATERSHED

Season	EVENT FLOWS					
	Rising Hydrograph (kg)	Descending Hydrograph (kg)	Non-Event Flows (kg)	Total Exports (kg)	% of Total	Unit Area Load (kg/ha)
			S O D I U M			
Fall, 1975	1.75 ± .01	17.06 ± 0.38	6.89 ± 92.03	25.70 ± 92.03	5.84	3.32
Winter, 1975-76	7.07 ± .09	6.25 ± 0.17	69.89 ± 155.56	83.21 ± 155.56	18.90	10.76
Spring Runoff 1976	60.37 ± .47	155.50 ± 19.94	39.22 ± 17.20	255.09 ± 26.34	57.94	33.00
Spring Post Runoff '76	6.51 ± .62	48.63 ± 8.87	18.06 ± 10.56	73.20 ± 13.80	16.63	9.47
Summer, 1976	0.75 ± .00001	1.22 ± 0.05	1.09 ± 0.18	3.06 ± 0.19	0.70	0.40
Total 75-76 Water Year	76.45 ± .78	228.66 ± 21.83	135.15 ± 181.87	440.26 ± 183.18		56.95
% of Total	17.36	51.94	30.70			
Fall, 1976	0	0	0	0	----	0
Winter 1976-77	0	0	0	0	----	0
Spring Runoff 1977	11.94 ± .08	18.87 ± 1.25	53.47 ± 16.79	84.28 ± 16.84	----	10.90
			C A L C I U M			
Fall, 1975	11.68 ± 0.04	53.18 ± 0.05	13.10 ± 8.37	77.96 ± 8.37	7.26	10.09
Winter, 1975-76	11.02 ± 0.14	17.02 ± 0.03	107.02 ± 86.29	135.06 ± 86.29	12.58	17.47
Spring Runoff 1976	78.93 ± 1.87	202.51 ± 1.86	156.01 ± 35.04	437.45 ± 35.14	40.73	56.59
Spring Post Runoff '76	56.24 ± 5.75	236.09 ± 2.90	92.23 ± 30.01	384.56 ± 30.69	35.81	49.75
Summer, 1976	13.27 ± 0.0001	20.87 ± 0.05	4.79 ± 1.44	38.93 ± 1.44	3.62	5.04
Total 75-76 Water Year	171.14 ± 6.05	529.67 ± 3.45	373.15 ± 98.22	1073.96 ± 98.46		138.93
% of Total	15.94	49.32	34.75			
Fall, 1976	0	0	0	0	----	0
Winter 1976-77	0	0	0	0	----	0
Spring Runoff 1977	13.43 ± 0.08	43.85 ± 0.21	85.52 ± 17.91	142.80 ± 17.91	----	18.47

It is not surprising that nitrogen concentrations in runoff are so low from this abandoned farm field since nitrogen is normally one of the primary limiting factors to terrestrial plant productivity. Inorganic N also is readily immobilized by plant uptake, and buildup in the organic content of soils in uncultivated fields or is rapidly lost by leaching to the groundwater.[5] In addition, nitrogen application rates were much lower in the late 1950's when this field was abandoned. Thus, any residual inorganic N would have long since been immobilized in the plant biomass, soil organic matter, or soil microbial community or would have been leached to groundwater. Conversely, total P concentrations would still be expected to be elevated because of greater suspended solids loads (TABLE 9-5) carried by the still functional drainage tile and the greater erodibility of oldfields compared to undisturbed forests.

The excellent agreement between results from this study and the nationwide survey are encouraging.[1] The loadings from this study (TABLES 9-2 to 9-6) can be extrapolated with some confidence to runoff from abandoned farm lands throughout the Great Lakes Basin.

Soil Analyses

Soil analyses from 1975 and 1976 also indicated the very low fertility of this abandoned farm land (TABLES 9-7,9-8). Both available (Bray extractable) phosphorus and nitrate were very low in these soils (TABLE 9-7). Both elements tended to decrease with depth with highest concentrations in the top 15 cm of soil where much of the root biomass and soil organic matter was located. The trend of decreased concentration with depth was much more apparent in 1975 than in 1976. Total kjeldahl N also followed the trend of decreases with depth with kjeldahl N being more than an order of magnitude greater in the highly organic surface soils (1095 μg/g dry soil in the top 5 cm) than at the 150 cm depth (68 μg/g dry soil). Analyses down to 300 cm were included in the 1975 sampling program; kjeldahl N continued to decrease to 34 μg/g dry soil at the 300 cm depth. Total P concentrations were also higher in the surface soils (342 ± 204 μg/g dry soil in the top 5 cm), decreased rapidly to 254 ± 221 μg/g dry soil in the 31-45 cm increment, then leveled off at a concentration of about 250 μg/g

TABLE 9-7. PHOSPHORUS, NITROGEN, AND CHLORIDE ANALYSES OF SOILS FROM THE BASELINE WATERSHED (VALUES IN μg/g DRY SOIL)

Depth (cm)	Bray Extractable P 1975	Bray Extractable P 1976	Total P* 1975	NO_3-N 1975	NO_3-N 1976	Kjeldahl N* 1975	Chloride 1975	Chloride 1976
0- 15	4.6	5.6	336	3.8	4.8	955	8.7	18.1
15- 30	2.5	5.0	283	3.0	4.1	599	4.4	15.4
30- 45	2.9	5.1	254	2.0	3.8	379	4.2	15.0
45- 60	2.4	4.9	245	1.8	3.8	247	3.8	15.9
60- 75	2.6	4.9	252	1.8	3.5	222	4.0	17.2
75- 90	2.3	6.0	282	1.8	3.4	178	4.3	14.7
90-105	2.6	4.8	277	1.8	4.4	134	4.2	15.6
105-120	2.2	3.8	283	1.8	3.8	102	4.1	16.6
120-135	1.9	3.5	236	1.6	3.3	81	4.0	16.6
135-150	1.3	3.0	231	1.6	3.3	68	4.1	15.9
AVERAGE	2.5	4.7	268	2.1	3.8	297	4.6	16.1

* No 1976 data.

TABLE 9-8. MAJOR EXCHANGEABLE CATION ANALYSES FOR 1976 FOR THE BASELINE WATERSHED SOILS (VALUES IN μg/g DRY SOIL)

Depth (cm)	Calcium	Magnesium	Sodium	Potassium
0- 15	1612	197	48	67
15- 30	1493	191	49	57
30- 45	1630	266	48	75
45- 60	1760	316	54	88
60- 75	1231	274	53	67
75- 90	1839	237	62	54
90-105	1967	207	66	61
105-120	2254	215	60	54
120-135	2309	190	58	58
135-150	2649	159	68	48
AVERAGE	1874	225	56	63

dry soil and remained at this level down to the 300 cm depth sampled in 1975.

Cation concentrations did not follow the trend of decreases with depth (TABLE 9-8). Instead, calcium tended to increase with depth while the other major cations showed no apparent trend (TABLE 9-8).

Chloride also followed the trend of higher concentrations in the top 15 cm of soil (TABLE 9-7), especially in 1975. Concentrations decreased from 12.9 ± 6.7 μg/g dry soil in the top 5 cm in 1975 to 5.7 ± 2.5 μg/g dry soil at the 11-15 cm increment, then leveled out at about 4 μg/g dry soil (TABLE 9-7). Thus, part of the apparent gradient with depth could have been the result of concentration by evapotranspiration in the top few cm of soil. At least part of the gradient in N and P may have been the result of interactions within the organic surface soils, but the weaker gradient in 1976 compared to 1975 indicated that evapotranspirational concentration from the surface few cm of soil was the prime mechanism responsible for the available P and NO_3-N gradients. The large differences in kjeldahl N with depth reflected the high organic content of surface soils, not just evapotranspirational concentration.

In summary, the soils were low in all major nutrients at all depths. The only major significant change in any nutrient with depth was kjeldahl N which decreased rapidly as expected from a high of 1095 μg/g dry soil in the organic surface soils to 34 μg/g in the deep, low organic content soils at 300 cm.

CONCLUSIONS

Abandoned farm lands are not major non-point sources of pollution. Nitrogen loadings from such watersheds approach background levels for undisturbed forests. Phosphorus loadings are higher and are intermediate between loadings from undisturbed forests and intensive agricultural lands. No remedial actions appear to be practicable or needed.

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SECTION 10

INTRODUCTION TO MILL CREEK STUDIES

A study of Mill Creek, a subwatershed of the Grand River basin was begun in 1974 as part of the Task C Pilot Watershed Studies of PLUARG. Mill Creek represents a watershed typical of the large fruit growing region of southwestern lower Michigan. Since fruit orchard farming utilizes some of the most intensive pesticide application rates of any agricultural practices in the Great Lakes Basin, it seemed particularly appropriate at the initiation of these studies to emphasize pesticide transport processes. Studies of nutrient exports were also included but not emphasized.

The pesticide transport process can be divided into two categories: (1) pesticide transported in solution, and (2) pesticide adsorbed to particulate matter and convected along with the sediment load of the stream. This distinction is necessary if one is to accurately identify the source of the problem.

The removal and subsequent transport of agricultural non-point source pollutants are directly related to the rainfall-runoff process. Overland flow is responsible for the initial movement of pollutants from the land surface to the stream. Once in the stream, the pollutant may be transported considerable distances by the stream flow. In the particular case of pesticides the quantity transported is related to the solubility and adsorptive characteristics of the pesticide considered. The translocation of pesticides that are adsorbed to or coated on sediment particles depends on the many variables influencing the capability of a stream to transport sediment, whereas those that are water soluble will be convected in amounts that are directly proportional to their concentration level and the stream discharge.

In view of the above description of the processes responsible for the transport of pesticides, the major objective of our research effort was to determine the relative amount of pesticide transported on the suspended solids and in solution. As a result of such a determination it would then be possible to ascertain the magnitude and source of this non-point source problem.

DESCRIPTION OF THE STUDY AREA

The Mill Creek watershed is located in midwestern lower Michigan. It includes Cranberry Lake and watershed. Mill Creek originates from Cranberry Lake at the Ottawa-Kent County line and flows southeasterly through Kent County, joining the Grand River at Comstock Park. Three major tributaries enter the creek (Figure 10-1). Upstream, the land is rolling with orchards and grain predominating. Proceeding downstream the creek goes from agricultural to urban development. In general the stream may be described as a cold water, usually clear creek with a drainage system representative of a midwestern agricultural and urban creek of moderate size and low relief gradient.

Initially, sampling of pesticides, sediments, and nutrients were conducted at nine stations established from Cranberry Lake to the creek's mouth as it enters the Grand River. Comprehensive analyses of some 57 pesticide parameters allowed the identification of problem pesticides and then concentration of efforts on the transport processes responsible for movement of these problem pesticides within and from the creek. After the initial survey of the entire watershed, studies were concentrated on the agricultural portion of the watershed upstream of station 5 at M-37 (Figure 10-1). Downstream of M-37, the watershed becomes urbanized with housing subdivisions, light industry, and a golf course -- land uses not indicative of the problem under investigation.

Land use in the 3058 ha watershed upstream of station 5 (Figure 10-1) is almost completely agricultural with about 90% of the area in cultivation and the other 10% in woodlots or wetlands. About 50% of the watershed is in corn, 30% in fruit orchards predominated by apples but with some cherries and other fruits, and the remaining 10% in pasture or alfalfa.

Almost 90% of the soils are loams or loamy sands (TABLE 10-1) of glacial origin. In general, the higher elevation soils are almost exclusively loam with Nester, Marlette, and Capac being the three predominant

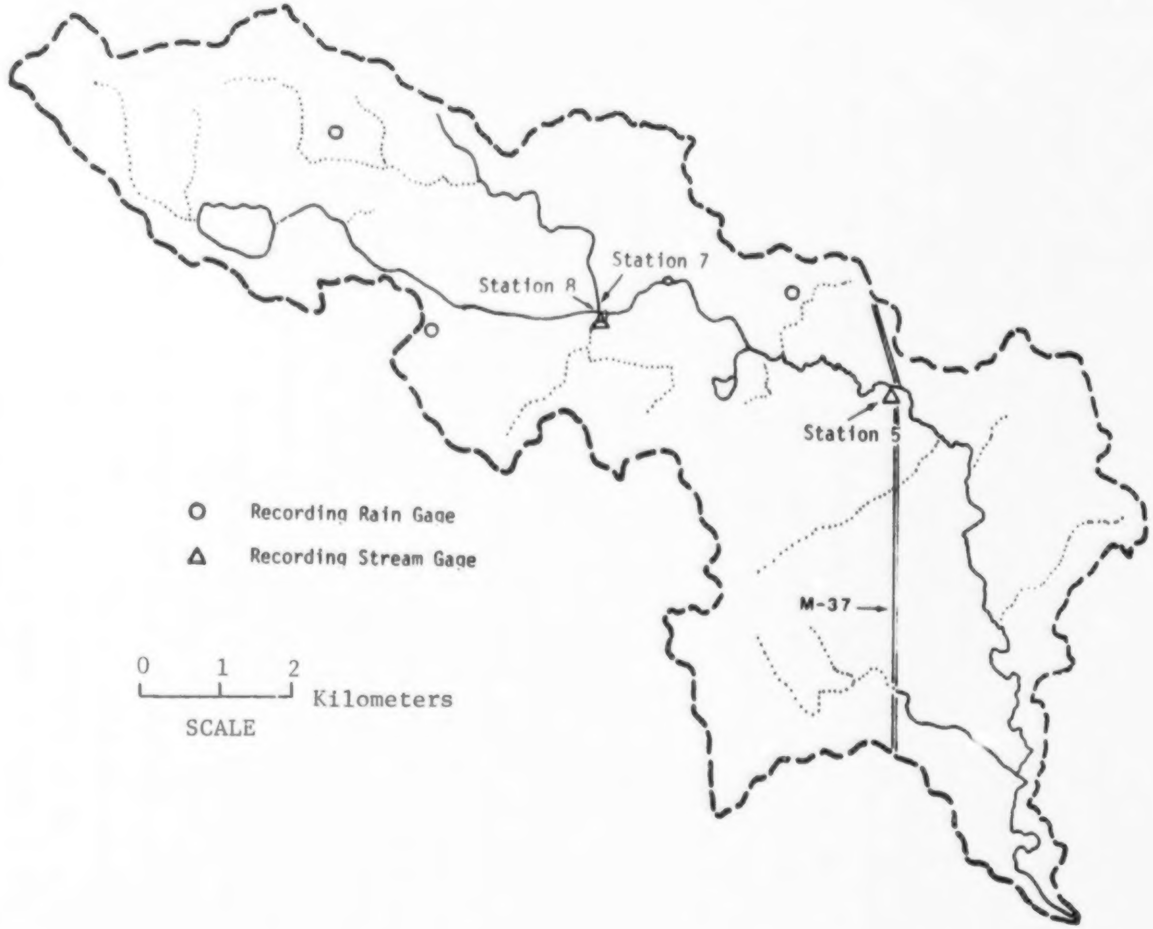
Station 8
Station 7
Station 5
M-37
○ Recording Rain Gage
△ Recording Stream Gage
0 1 2 Kilometers
SCALE

Figure 10-1. Mill Creek watershed.

TABLE 10-1: MAJOR SOILS OF THE 3058 ha MILL CREEK WATERSHED

Soil	Area (ha)	Percent of Total
Loam	2,242	73.3
Loamy Sand	489	16.0
Muck	153	5.0
Sandy Loam	99	3.2
Alluvial Land	30	1.0
Fine Sandy Loam	6	0.2
Fine Sand	4	0.1
(Lakes)	35	1.1

soil types. In the areas adjacent to the streams, the soils are almost all loamy sands predominately of the Spinks, Brady, Oshtemo, and Chelsea series interspersed with pockets of muck, sandy loam, fine sandy loam and other alluvial lands (TABLE 10-1). Slopes are generally in the 2 to 12% range with some ridges in the 12-18% range.

Locations of major sampling stations are shown in Figure 10-1. There were three subwatersheds sampled with automatic (ISCO) sequential stormwater samplers so that loadings of major pesticides, sediments, and nutrients could be calculated. These three stations include (1) the 889 ha North Branch watershed (station 7, Figure 10-1), (2) the 1146 ha upper Mill Creek watershed prior to its confluence with North Branch (station 8, Figure 10-1), and (3) the entire 3058 ha agricultural portion of Mill Creek upstream of the urban area (station 5, Figure 10-1). Precipitation on the watershed was monitored with three recording rain gauges (Figure 10-1).

Detailed descriptions and discussions of the methods, results and discussion, and conclusions from studies of nutrient export, suspended sediment movement, and pesticide transport processes and exports will be presented in Sections 11, 12, and 13.

SECTION 11

NUTRIENT EXPORTS FROM THE MILL CREEK WATERSHED

T.M. Burton and C.S. Annett

INTRODUCTION

The Mill Creek Watershed Study had as its basic objective the quantification of pesticide exports from a "typical" watershed in the fruit growing region of southwestern lower Michigan. Nevertheless, some studies of nutrient export were included since nutrient export from fruit growing regions within the Great Lakes Basin have not been characterized very well. While these studies were limited, enough data were collected to broadly characterize the nutrient export from such watersheds. This section is a report on these limited nutrient export studies.

MATERIALS AND METHODS

The general description of the Mill Creek Watershed Study has already been given (Section 10). The sampling procedure consisted of taking aliquots of water from the pesticide-suspended sediment samples collected by an automatic pump sampler (ISCO, Model 1392). The sampler was turned on by a rise in stream level by an automatic device. The sampler then took 28 separate samples over a 48 hour period. Each separate sample actually consisted of eight subsamples pumped into a 3.8 ℓ glass jug at 12.38 minute intervals. Thus, each sample represented a 1.7 hour "composite" sample of stream water. These automatic pump samples were taken at stations 5, 7, and 8 (Figure 10-1) and were supplemented by grab samples taken during maintenance trips to the watershed (see Sections 12 and 13 for a more detailed description of the sampling protocol). Because first priority of analyses was placed on pesticide and suspended sediment analyses, only a limited number of nutrient samples were analyzed. There were enough runoff event samples to characterize the export of nutrients during the limited number of runoff events that occurred during the two years of this study (1975-76 and 1976-77). However, low flow sampling was very limited and the very large errors associated with estimates of export during non-runoff events resulted in fairly large mean error terms for annual exports. Nevertheless, the resulting data do give a "ball park" estimate of runoff from this type of mixed fruit orchard-corn land use within the Great Lakes Basin.

All analytical methods followed the techniques agreed upon by the International Joint Commission (IJC). Basically, all techniques followed standard auto-analyzer techniques[1] or Standard Methods.[2] Inter-Laboratory comparisons showed that our analytical techniques were comparable to those used by other laboratories associated with the Pilot Watershed Studies of IJC.

RESULTS AND DISCUSSION

Enough samples were taken at station 5 (Figure 10-1) to enable us to calculate annual loading using both event and non-event strata (TABLE 11-1). The events were sampled often enough that good estimates of exports on the rising and falling limb of the hydrograph could be calculated (TABLE 11-1). However only a few non-event samples were taken. Thus, mean errors associated with non-event estimates in both water years are often equal to or greater than the mean value. This large non-event error term results in a fairly large error term associated with the annual estimate as well. This large error term results to a great degree from the method of calculation. Well over 50% of most constituents are exported in runoff events where the error is very small. Thus, the annual export figure is in the right "ball park" at least and is probably a much better estimate than the error term would indicate. For this particular case, using the unbiased flow weighted mean concentration times the mean annual flow (no within year stratification), as was done for the summary pilot watershed report,[3] results in lower error terms for some of the constituents. The two different estimates are reasonably close for all constituents (TABLE 11-2). In particular, the phosphorus and nitrogen estimates are very close using the two

TABLE 11-1: NUTRIENT EXPORTS FROM THE 3058 ha MILL CREEK WATERSHED

	EVENT FLOWS				
	Rising Hydrograph (kg)	Descending Hydrograph (kg)	Non-Event Flows (kg)	Total Exports (kg)	Unit Area Loads (kg/ha)
		1975-1976	WATER YEAR		
Total Phosphorus	130.62 ± 0.01	943.28 ± 0.84	676.56 ± 1,714	1,750 ± 1,714	0.57
Ortho Phosphorus	17.41 ± 0.003	657.18 ± 0	392.30 ± 976.01	1,067 ± 976	0.35
Nitrate-Nitrogen	833 ± 0.1	12,418 ± 6	8,287 ± 714	21,538 ± 714	7.04
Nitrite-Nitrogen	26.65 ± 0.003	97.31 ± 0.02	107.16 ± 0.00001	231 ± 0.003	0.08
Ammonia-Nitrogen	32.6 ± 0.004	1,261.0 ± 0.01	287.8 ± 119	1,581 ± 119	0.52
Kjeldahl-Nitrogen	524 ± 0.1	6,780 ± 3	4,354 ± 238	11,658 ± 238	3.81
Chloride	10,756 ± 2	34,214 ± 9	114,135 ± 196,392	159,105 ± 196,392	52.03
Calcium	51,460 ± 9	510,891 ± 358	448,175 ± 26,186	1,010,526 ± 26,188	330.45
Sodium	5,185 ± 1	48,249 ± 41	50,552 ± 2,619	103,986 ± 2,619	34.01
		1976-1977	WATER YEAR		
Total Phosphorus	246.48 ± 0.09	682.65 ± 18.19	317.00 ± 1,661.37	1,246 ± 1,661	0.41
Ortho Phosphorus	135.78 ± 0.07	353.62 ± 15.75	224.73 ± 295.32	714 ± 296	0.23
Nitrate-Nitrogen	3,654 ± 1	8,096 ± 93	3,220 ± 1,429	14,970 ± 1,429	4.90
Nitrite-Nitrogen	9.06 ± 0.004	17.54 ± 0.35	20.88 ± 0.00001	47 ± 0.4	0.02
Ammonia-Nitrogen	39.7 ± 0.01	25.7 ± 0.3	100.9 ± 185.8	166 ± 186	0.06
Kjeldahl-Nitrogen	930 ± 0.4	2,323 ± 53	1,565 ± 1,718	4,818 ± 1,719	1.58
Chloride	22,885 ± 8	36,114 ± 24	44,107 ± 39,789	103,106 ± 39,789	33.72
Calcium	99,478 ± 0	151,020 ± 735	200,902 ± 71,195	451,400 ± 71,199	147.61
Sodium	10,217 ± 0	20,104 ± 105	18,608 ± 17,328	48,929 ± 17,328	16.00

TABLE 11-2: COMPARISON OF ANNUAL ESTIMATES FOR THE 3058 ha MILL CREEK WATERSHED CALCULATED WITH EVENT VERSUS NON-EVENT STRATA AND CALCULATED WITHOUT STRATIFICATION

		Event Strata Used	No Within Year Strata
1975-76	Total Phosphorus	1,750 ± 1,717	1,782 ± 1,018
	Ortho Phosphorus	1,067 ± 976	882 ± 298
	Nitrate-Nitrogen	21,538 ± 714	20,573 ± 5,546
	Nitrite-Nitrogen	231 ± 0.003	288 ± 285
	Ammonia-Nitrogen	1,581 ± 119	912 ± 1,023
	Kjeldahl-Nitrogen	11,658 ± 238	9,116 ± 2,295
	Chloride	159,105 ± 196,392	137,303 ± 23,509
	Calcium	1,010,526 ± 26,188	579,095 ± 111,673
	Sodium	103,986 ± 2,619	63,901 ± 8,939
1976-77	Total Phosphorus	1,246 ± 1,661	1,008 ± 331
	Ortho Phosphorus	714 ± 296	582 ± 250
	Nitrate-Nitrogen	14,970 ± 1,429	11,786 ± 3,496
	Nitrite-Nitrogen	47 ± 0.4	31 ± 4
	Ammonia-Nitrogen	166 ± 186	63 ± 28
	Kjeldahl-Nitrogen	4,818 ± 1,719	3,602 ± 1,090
	Chloride	103,106 ± 9,789	63,863 ± 8,334
	Calcium	451,400 ± 71,199	165,439 ± 56,926
	Sodium	48,929 ± 17,328	19,293 ± 3,644

techniques. The chloride estimate for 1975-76 and the ammonia estimate for 1976-77 are the only two cases where less than 50% of annual export was associated with low or non-event flow (TABLE 11-1). In both cases, the error term with the non-event flow is very inflated and the estimate using the no stratification technique gives a somewhat lower but comparable estimate with a much lower error term. It would appear that the loadings for this watershed do not change much regardless of computational technique and represent reasonable approximations of annual loading from the watershed.

Total phosphorus and ortho phosphorus exports were higher than the mean exports expected for land use with about 90% agriculture based on the recent nationwide survey[4] but are well within the range of total phosphorus exports reported from other agricultural watersheds in the Great Lakes Basin.[5] Nitrate nitrogen exports were very near the 7.8 kg N/ha reported in the nationwide survey[4] in 1975-76 and somewhat lower in the drier

1976-77 water year (TABLE 11-1). Thus, it would appear that this mixed fruit orchard-corn watershed exports about the same quantity of nutrients as do other types of agricultural watersheds in the Great Lakes Basin.

Enough data were collected at stations 7 and 8 (Figure 10-1) to calculate annual loading from these stations as well. These data were computed using a mean daily stratification technique since there was not enough data to justify event versus non-event stratification. These data are characterized by inflated error terms (TABLES 11-3 and 11-4). The non-stratification technique used in the summary pilot watershed report[3] gave lower error terms for most constituents and probably represents more reasonable estimates for these subwatersheds (TABLE 11-5). Both computational techniques produced fairly similar estimates. These data represent fairly crude estimates but again fall in the range expected for agricultural watersheds.[4,5] Thus, the fact that 30% of this watershed is in fruit orchards versus the more traditional corn cultivation typical of much of the midwest has not resulted in great differences in quantity of nutrients exported compared to other midwestern and Great Lakes watersheds.[4,5]

CONCLUSIONS

The Mill Creek watershed loses about the same quantity of nutrients per year as do other agricultural watersheds in the Great Lakes Basin. These losses could, no doubt, be reduced somewhat by adoption of best management practices, streambank erosion prevention techniques, etc. All of these procedures will require long-term educational and financial commitments. No short term remedial action appears appropriate.

TABLE 11-3: NUTRIENT EXPORTS FROM THE 1146 ha MILL CREEK WATERSHED ABOVE THE CONFLUENCE WITH NORTH BRANCH

	Flow Weighted Mean Concentration (mg/ℓ)	Total Exports (kg)	Unit Area Loads (kg/ha)
	1975-76	WATER YEAR	
Total Phosphorus	0.099	223 ± 6	0.195
Ortho Phosphorus	0.037	83.3 ± 3.7	0.073
Nitrate-Nitrogen	0.958	2,165 ± 21	1.889
Nitrite-Nitrogen	0.040	90.3 ± 0	0.079
Ammonia-Nitrogen	0.039	87.3 ± 2.6	0.076
Kjeldahl-Nitrogen	0.569	1,285 ± 24	1.121
Chloride	19.436	43,897 ± 6,314	38.305
Calcium	73.769	166,612 ± 526	145.386
Sodium	9.640	21,772 ± 1,421	18.998
	1976-77	WATER YEAR	
Total Phosphorus	0.037	18 ± 125	0.016
Ortho Phosphorus	0.031	15 ± 95	0.013
Nitrate-Nitrigen	0.758	373 ± 243	0.326
Nitrite-Nitrogen	0.009	4.44 ± 0	0.004
Ammonia-Nitrogen	0.014	6.9 ± 0	0.006
Kjeldahl-Nitrogen	0.453	223 ± 450	0.195
Chloride	26.725	13,175 ± 21,209	11.497
Calcium	87.500	43,137 ± 0	37.611
Sodium	9.150	4,511 ± 0	3.936

TABLE 11-4: NUTRIENT EXPORTS FROM THE 889 ha NORTH BRANCH SUBWATERSHED OF MILL CREEK

	Flow Weighted Mean Concentration (mg/ℓ)	Total Exports (kg)	Unit Area Loads (kg/ha)
	1975-76	WATER YEAR	
Total Phosphorus	0.105	206 ± 5,210	0.232
Ortho Phosphorus	0.057	112 ± 16	0.126
Nitrate-Nitrogen	0.963	1,894 ± 63,954	2.131
Nitrite-Nitrogen	0.013	26.2 ± 437.4	0.030
Ammonia-Nitrogen	0.090	177.5 ± 2.1	0.200
Kjeldahl-Nitrogen	0.745	1,465 ± 15,830	1.648
Chloride	11.552	22,719 ± 35,356	25.556
Calcium	51.275	100,839 ± 117,815	113.430
Sodium	4.460	8,770 ± 23,478	9.865
	1976-77	WATER YEAR	
Total Phosphorus	0.223	98 ± 875	0.110
Ortho Phosphorus	0.159	70 ± 386	0.079
Nitrate-Nitrogen	3.100	1,368 ± 9,256	1.539
Nitrite-Nitrogen	0.009	3.92 ± .00001	0.004
Ammonia-Nitrogen	0.022	9.51 ± 124	0.011
Kjeldahl-Nitrogen	0.875	386 ± 914	0.434
Chloride	17.203	7,590 ± 20,905	8.538
Calcium	59.827	26,395 ± 104,981	29.691
Sodium	4.545	2,005 ± 9,972	2.255

TABLE 11-5: COMPARISON OF ANNUAL ESTIMATES COMPUTED USING MEAN DAILY LOADINGS VERSUS ESTIMATES COMPUTED WITH NO STRATIFICATION FOR THE NORTH BRANCH WATERSHED AND FOR THE MILL CREEK WATERSHED ABOVE THE CONFLUENCE WITH NORTH BRANCH

		Daily Strata Used	Annual Estimates Only
		--------- NORTH BRANCH	WATERSHED ---------
1975-76	Total Phosphorus	206 ± 5,210	506 ± 335
	Ortho Phosphorus	112 ± 16	217 ± 99
	Nitrate-Nitrogen	1,894 ± 63,954	3,529 ± 1,433
	Nitrite-Nitrogen	26 ± 437	113 ± 137
	Ammonia-Nitrogen	176 ± 2	215 ± 229
	Kjeldahl-Nitrogen	1,465 ± 15,830	2,063 ± 938
	Chloride	22,719 ± 33,356	40,246 ± 13,602
	Calcium	100,839 ± 117,815	159,078 ± 42,395
	Sodium	8,770 ± 23,478	19,811 ± 5,105
1976-77	Total Phosphorus	98 ± 875	35 ± 14
	Ortho Phosphorus	70 ± 386	32 ± 13
	Nitrate-Nitrogen	1,368 ± 9,256	586 ± 66
	Nitrite-Nitrogen	4 ± 0	6 ± 11
	Ammonia-Nitrogen	10 ± 124	7 ± 0.3
	Kjeldahl-Nitrogen	386 ± 914	229 ± 52
	Chloride	7,590 ± 20,905	19,602 ± 1,169
	Calcium	26,395 ± 104,981	-----
	Sodium	2,005 ± 9,972	-----
		- MILL CREEK WATERSHED	ABOVE NORTH BRANCH -
1975-76	Total Phosphorus	223 ± 6	478 ± 238
	Ortho Phosphorus	83 ± 4	216 ± 105
	Nitrate-Nitrogen	2,165 ± 21	5,200 ± 2,836
	Nitrite-Nitrogen	90 ± 0	44 ± 41
	Ammonia-Nitrogen	87 ± 3	344 ± 416
	Kjeldahl-Nitrogen	1,285 ± 24	2,745 ± 731
	Chloride	43,897 ± 6,314	33,986 ± 4,377
	Calcium	166,612 ± 526	146,055 ± 25,920
	Sodium	21,772 ± 1,421	13,012 ± 1,605
1976-77	Total Phosphorus	18 ± 125	179 ± 109
	Ortho Phosphorus	15 ± 95	113 ± 43
	Nitrate-Nitrogen	373 ± 243	4,061 ± 2,316
	Nitrite-Nitrogen	4 ± 0	7 ± 2
	Ammonia-Nitrogen	7 ± 0	9 ± 12
	Kjeldahl-Nitrogen	223 ± 450	851 ± 301
	Chloride	13,175 ± 21,209	13,954 ± 2,969
	Calcium	43,137 ± 0	31,913 ± 15,662
	Sodium	4,511 ± 0	2,757 ± 1,256

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SECTION 12

MILL CREEK SUSPENDED SEDIMENT STUDIES

R.E. Snow, D.A. McIntosh, and T.M. Burton

INTRODUCTION

The importance of suspended sediments as a pollutant in streams and as an agent of transport of nutrients, pesticides, and heavy metals is a well recognized phenomenon.[1-7] In fact, the large majority of phosphorus entering a stream arises from soil erosion,[8] as do many of the pesticides.[9-10] The selective nature of surface runoff with respect to removal of fine soil particulates is very important since a large percentage of both phosphorus and pesticides are associated with clay-sized particles or with the small particulate organic particles that are most easily transported.[8,13-15] These fine suspended and colloidal sized particles that are selectively eroded to the stream are the most active in adsorption, are readily transported by even low energy flow and are fairly stable in suspension in streams. Thus, it is very important when studying runoff of easily sorbed nutrients such as phosphorus or when studying pesticides to include studies of suspended sediment losses from a watershed and to try to correlate this sediment loss with pesticide and nutrient losses. An understanding of the role of sediments in pesticide or nutrient loss is also highly desirable as a means of predicting losses[16] and as a means of controlling such non-point source pollution.[5,6] In fact, many of the best management practices for controlling non-point source pollution from agriculture, urban areas, etc., emphasize control of sediment losses by such practices as no-till farming, construction of detention basins, contour plowing, green belts, etc.[5]

Since quantification of pesticide losses from a "typical" fruit orchard area of Michigan was the primary objective of the Mill Creek Watershed

Study and since most pesticides are lost from watersheds and transported in streams on eroded soil particles, an important secondary objective of the Mill Creek Watershed Study was the quantification of suspended sediment losses and an attempt to correlate these losses to pesticide exports. The basic questions dealing with export of sediments will be included in this section, while the suspended sediment-pesticide correlations will be discussed in the following section (Section 13).

MATERIALS AND METHODS

Suspended sediment samples were collected using two different techniques at stations 5, 7, and 8 (Figure 10-1). In the first technique, an automatic pump sampler (ISCO, Model 1392) collected samples over an entire storm event. Sampling was initiated by a custom built device which turned the sampler on as stream level rose.[17] The automatic sampler was modified to pump into a 3.8 ℓ glass bottle. Each 3.8 ℓ glass bottle was filled by pumping equal amounts at eight different periods (every 12.83 minutes) over a 1.7 hour period with alternate samples used for pesticide or sediment analyses.

The second sampling technique involved use of a custom built, less streamlined modification of the standard U.S. Geological Survey DH-48 wading rod sampler (refer to p. 152-153, Gregory and Walling[18]). Due to lack of streamlining, the intake nozzle had to be extended further in front of the bottle with the exhaust nozzle being an extended elbow nozzle. Laboratory tests showed that these modifications overcame the lack of streamlining and this custom-built sampler took samples comparable to those taken with a U.S. Geological Survey DH-48 sampler. At first, samples were taken by moving the sampler vertically through depth of the stream to obtain depth integrated samples. However, field comparisons indicated that several samples taken at different depths were somewhat better at characterizing higher concentration gradients. Both techniques gave comparable results at lower concentrations. Thus, most hand held sampling was done by integrated point samples. The hand held sampler also gave results comparable to the ISCO sampler.[19] More detailed information on sampling techniques, comparability of sampling devices, etc., is available from R.E. Snow's M.S. thesis.[19] Most data were collected from station 5 (Figure 10-1) and this data will be emphasized in the following discussion since it represents output from the whole watershed.

Suspended sediment analyses followed the method outlined in Standard Methods[20] with only minor modifications.[19] Some particle size analyses were also conducted using a Coulter Counter Model A. The Coulter Counter was used to obtain a rough indication of size of particles less than 100 microns in diameter. Larger particles were examined by light microscope to determine an average diameter and range.

Hydrologic data were collected with Steven's Type A-71 stage-height recorders and were converted to discharge using stage-discharge relationships established by repeated measurement with current meters under a variety of flow conditions. These data were collected for us by Paul Bent, a retired U.S. Geological Survey hydrologist with considerable experience at hydrologic measurements, using standard U.S. Geological Survey procedures. Precipitation data were collected from three sites using Bendix recording rain gauges (Figure 10-1).

RESULTS AND DISCUSSION

Suspended sediment export for the entire 3058 ha Mill Creek watershed (station 5, Figure 10-1) was studied intensively during the 1975-76 water year.[19] The suspended sediment concentration and discharge data were used to develop a stream discharge versus suspended sediment discharge transport relationship (Figure 12-1). The least squares fit to these data resulted in the following equation:

$$Q_s = 0.0078Q^{1.81} \tag{1}$$

where Q_s is suspended sediment discharge and Q is stream discharge. Because orchard watersheds have a smaller percentage of tilled land, sediment available for transport is reduced and the coefficient in the sediment transport equation is smaller than the coefficient of 0.05 expected for a row-cropped midwestern watershed.[21] In addition, the Mill Creek channel has considerable foliage along the stream banks which would further reduce the coefficient. The exponent in the equation describes the rate at which

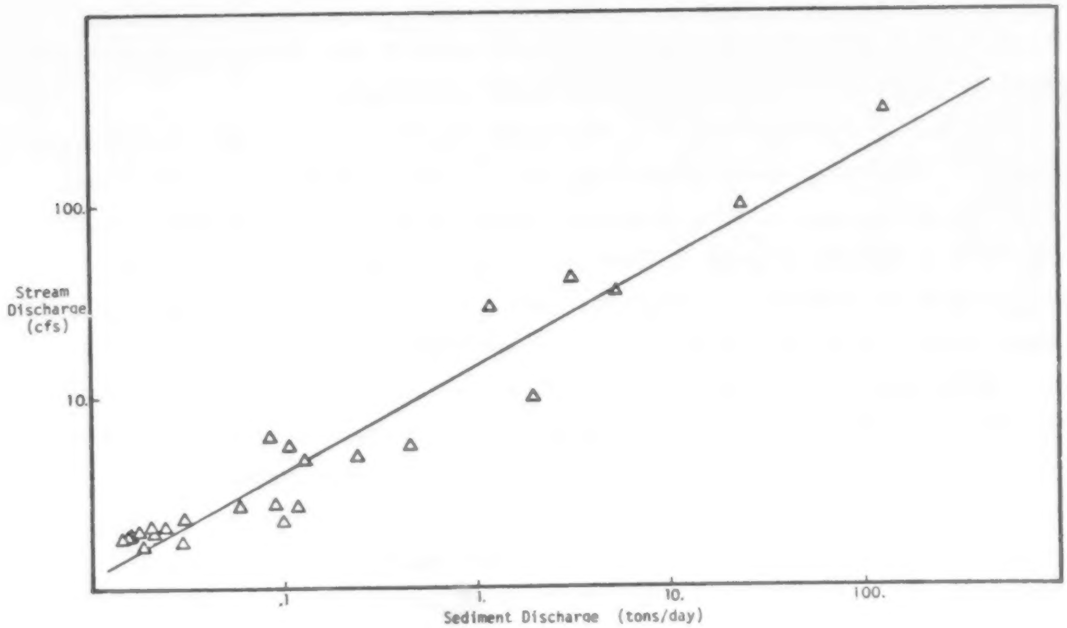


Figure 12-1. The suspended sediment versus stream discharge relationship for Mill Creek at station 5 (see Figure 10-1 for station location). This station drains the 3058 ha Mill Creek watershed.

suspended sediment export increases with stream discharge. For large, western watersheds, the exponent can be as high as three. Test plots in the midwest have a relationship in which the exponent is between one and two.[21] For a small to medium-size midwestern watershed, an exponent of 1.81 seems reasonable.

The sediment yield or total sediment loss during a year was computed with the aid of the suspended sediment transport curve as well as measurements made during unsteady flow. In addition to the suspended load, the bed load had to be estimated to obtain the total sediment yield.

The method used to estimate the bed load was developed by Colby[22] and has been utilized by the U.S. Bureau of Reclamation. The procedure required the mean stream velocity, stream width, mean depth, the measured mean suspended sediment concentration and the concentration of the bed sediment. The first three parameters were obtained by direct measurement or by establishing correlations between stream discharge and each parameter. For

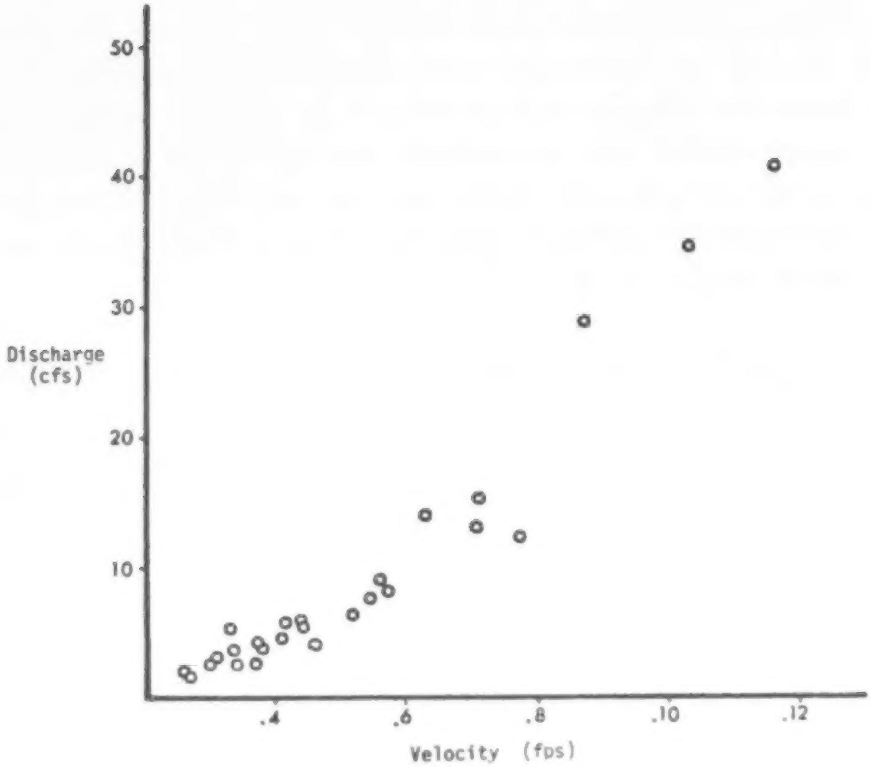


Figure 12-2. The stream discharge-stream velocity relationship for Mill Creek at station 5 (see Figure 10-1 for station location). This station drains the 3058 ha Mill Creek watershed.

example, the mean stream velocity was determined from the stream discharge data using the relationship between stream discharge and velocity (Figure 12-2). Mean depth and width were also estimated from known relationships between stream stage height and each parameter. Suspended sediment concentrations were measured directly or estimated from stream discharge-suspended sediment correlations. The concentrations of bed sediment were determined by extending the suspended sediment profile to the stream bed and estimating the concentration.

Using direct measurements and the stream discharge-suspended sediment transport curve (Figure 12-1), suspended sediment export for the 1975-76 water year was computed to be 663 metric tons for the whole watershed

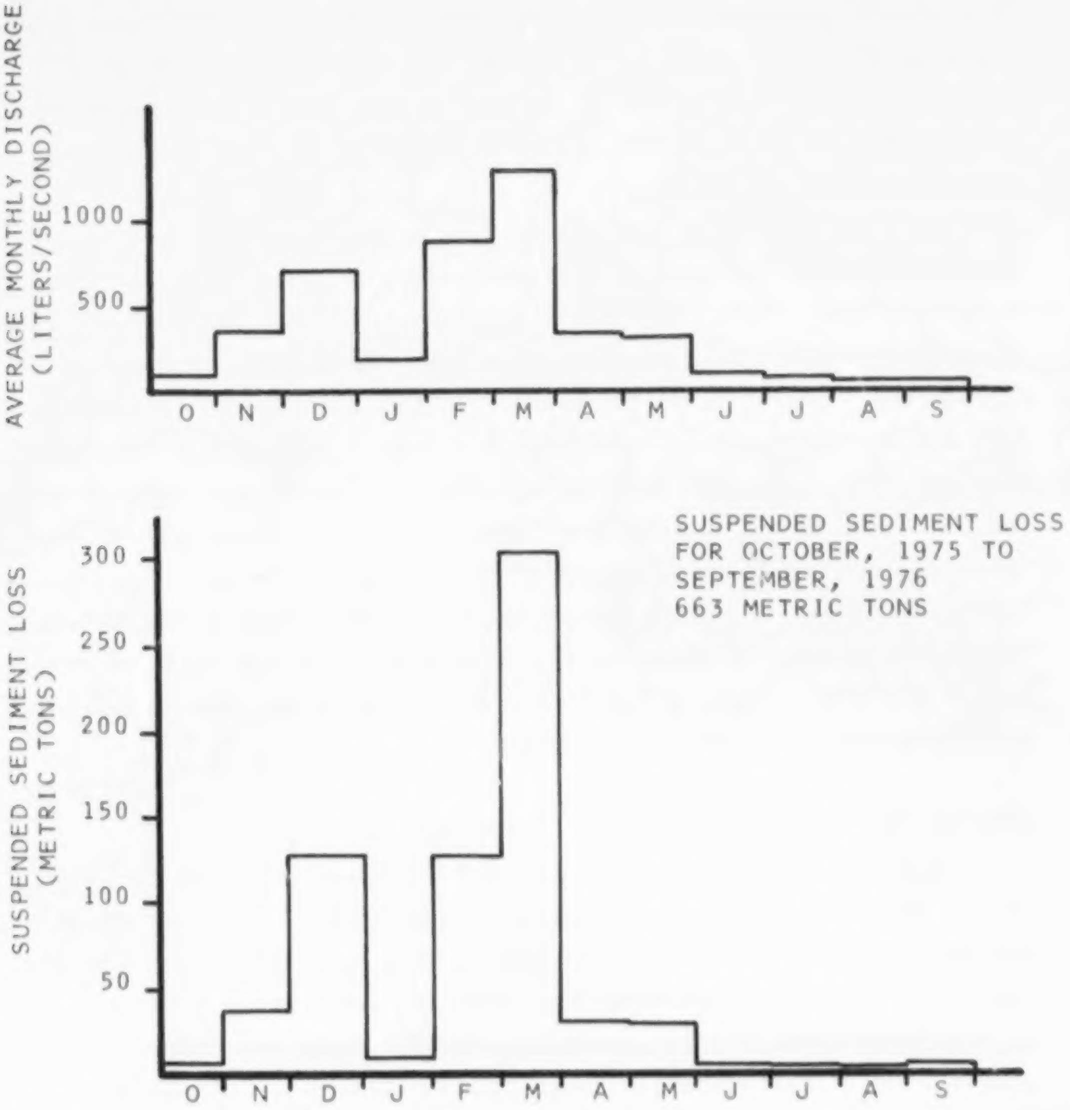
(TABLE 12-1) or 217 kg/ha. Bed load was computed to be 59 metric tons or 19 kg/ha. Thus, total sediment yield for this water year was 236 kg/ha or 722 metric tons for the entire watershed. The 1975-76 water year was a period of lower than average precipitation (58 cm versus a normal 76 cm). Thus, suspended sediment loss was probably less than normal because of lower than normal precipitation during the last four months of the year. This low precipitation resulted in very low sediment yields during the last four months (Figure 12-3).

TABLE 12-1: DISCHARGE VERSUS SEDIMENT EXPORT FOR THE 3058 ha MILL CREEK WATERSHED FOR THE 1975-76 WATER YEAR

Month	Mean Monthly Discharge (ℓ/second)	Monthly Suspended Sediment Export (metric tons)
October, 1975	108	4
November, 1975	273	36
December , 1975	627	128
January, 1976	181	6
February, 1976	869	126
March, 1976	1339	302
April, 1976	333	28
May, 1976	352	27
June, 1976	140	2
July, 1976	86	1
August, 1976	60	1
September, 1976	55	2
TOTAL		663

Annual sediment yield from watersheds in the midwest vary from 245 kg/ha to 3150 kg/ha.[21] Mill Creek's annual sediment yield was 236 kg/ha for 1975-76, a reasonable figure considering the large percentage of orchard farming with its associated low tillage rate, the vegetation along the streambank, and the lower than normal precipitation for this year.

Some limited suspended sediment data were also taken along with the pesticide analyses in 1976-77 after the end of R.E. Snow's intensive study.[19] The 1976-77 data were calculated using the Beale ratio estimator technique and runoff event versus non-event strata for the water year.



SUSPENDED SEDIMENT LOSS
FOR OCTOBER, 1975 TO
SEPTEMBER, 1976
663 METRIC TONS

Figure 12-3. Mean monthly stream discharge and suspended sediment losses from the 3058 ha Mill Creek watershed (station 5, Figure 10-1).

Since runoff events were emphasized in the sampling program, the non-event stratum was characterized by an extremely large mean error term. Nevertheless, annual loading for the entire watershed was 750 metric tons (± 5965) resulting in an annual unit area loss of 245 kg/ha, a figure extremely close to the 217 kg/ha estimate from the more intensive study of 1975-76. Thus, annual suspended sediment loss from the Mill Creek watershed would appear to be on the order of 220 to 250 kg/ha during dry years such as 1975-76 and 1976-77. Losses during wetter years would be expected to be greater, but still on the low end of losses expected from midwestern watersheds (245 to 3150 kg/ha).[21]

Some crude particle size analyses were also done with the Coulter Counter and with examination under a microscope. These analyses were done on samples taken during the fairly low flow conditions of 110 to 180 ℓ/sec (Figure 12-4). The mean particle size under these conditions was about 35 microns. The intake on the Coulter Counter excluded particles greater than 100 microns in size. Examination of 130 of these particles showed that the mean sand sized fraction was 140 ± 70 microns in size with particles as large as half a millimeter being included. Particles transported under low flow conditions are primarily the small, fine sand and silt particles (Figure 12-4) with a few larger sand sized particles being included. Of course, as flow increased to the large flows characteristic of spring runoff and large storms (greater than 1000 ℓ/sec), the size of particles transported would increase accordingly.

CONCLUSIONS

Suspended sediment losses from the Mill Creek watershed for 1975-76 and 1976-77 were 217 and 245 kg/ha, respectively. The calculated bed load loss for 1975-76 was 19 kg/ha. Thus, annual sediment losses during the course of this study were very low compared to other midwestern watersheds.[21] One of the reasons for these low losses was probably the low streambank erosion due to considerable streambank vegetation and streambank treatment by landholders.[23] In fact, Mildner[23,24] estimated a total loss of sediment from streambank erosion in Mill Creek as 150 metric tons per year. His estimates were for the entire watershed, whereas our estimates were for only the upper 58% of the watershed. If all areas were contributing equally, the loss from the upstream area from streambank erosion would be 87 metric tons or 12% of the 722 metric tons lost in 1975-76. This percentage is about twice the 4 to 6% of total sediment yield estimated by Mildner.[24]

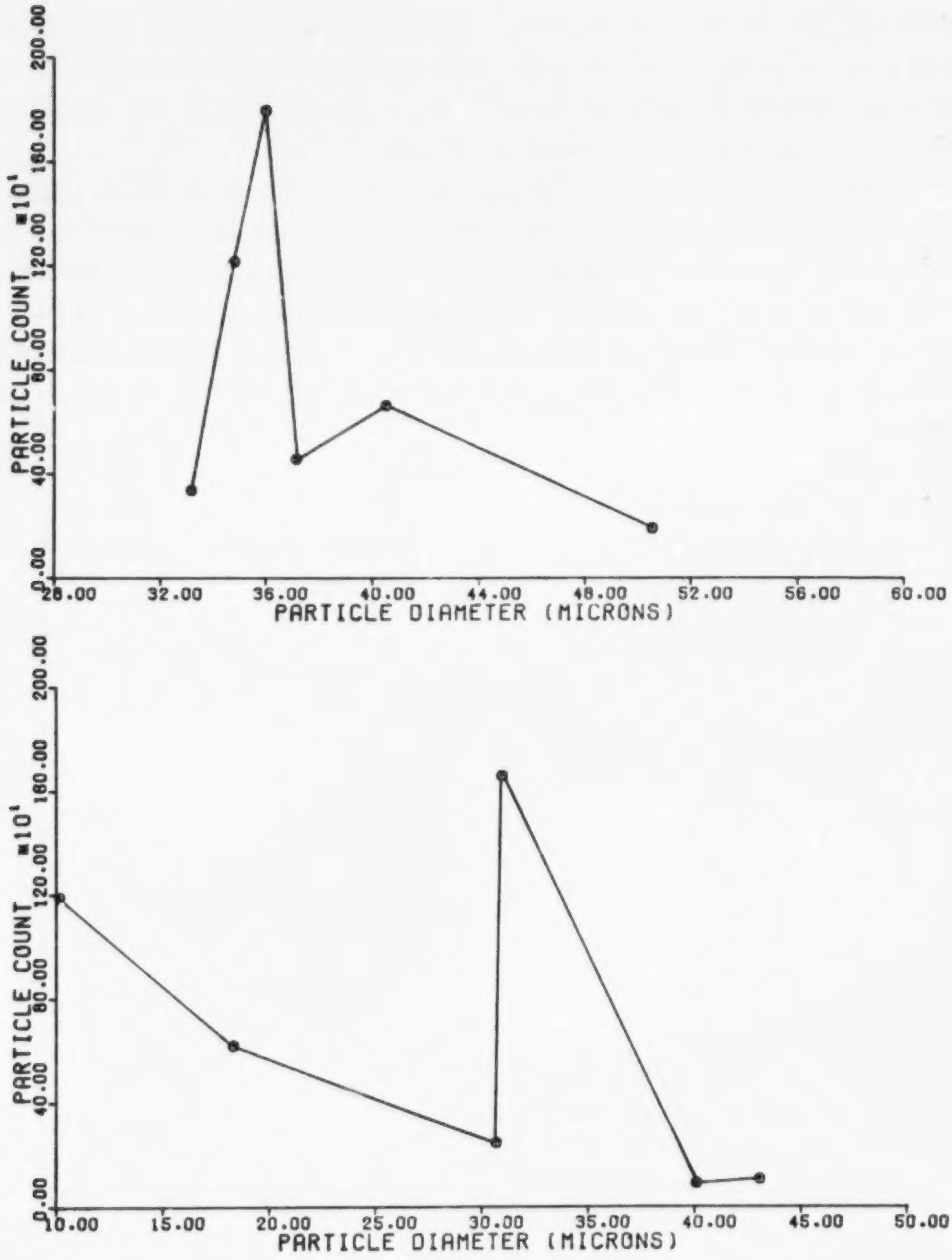


Figure 12-4. Particle size distribution of particles less than 100 microns in size transported during low flow periods on October 28, 1976 (flow = 110 ℓ/sec, upper figure) and on November 28, 1976 (flow = 189 ℓ/sec, lower figure). These size distributions were determined with a Coulter Counter, Model A.

A second reason for the low sediment losses was the low tillage rate associated with orchards. A third reason was the lower than average precipitation rate. Suspended sediment losses were on the low end of the range of losses to be expected from midwestern watersheds.[21]

Remedial actions needed to reduce sediment losses are minimal. Some streambank erosion control measures could be taken, but most needed treatment has been installed.[23] Adoption of best management practices within the watershed could also further reduce sediment losses to some extent. However, sediment losses are already very low and adoption of further control measures for this watershed might not be worthwhile from an economic standpoint.

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SECTION 13

MILL CREEK PESTICIDE STUDIES

Matthew J. Zabik

INTRODUCTION

Mill Creek (Figure 13-1) is located in midwestern lower Michigan. It originates in Cranberry Lake and flows southeasterly through Kent County, joining the Grand River at Comstock Park. Three tributaries enter the Creek. The Creek varies in width from dried up to seven meters. Upstream the land is rolling with orchards and grain predominating, proceeding downstream the Creek goes from agricultural to urban development. In general, the Creek may be described as a cold water, usually clear creek with a drainage system representative of a midwestern agricultural and urban creek of moderate size and low relief gradient.

Sampling Stations

Nine permanent sampling stations (Figure 13-1) were established from Cranberry Lake to the Creek's mouth as it enters the Grand River. The stations were primarily selected to determine pesticide input from its tributaries and to determine any changes in pesticide content as the Creek goes from agricultural to urban development.

Station 1 is located at the mouth of Mill Creek where it enters the Grand River. The bottom material at this station consists of sand with a very low percentage of organic material. The bottom is almost devoid of any aquatic vegetation and aquatic organisms are scarce. Some of the organisms found were gastropods representing the Mollusks, Isopods and amphipods representing the Crustaceans, and Diptera, Hemiptera and Coleoptera representing the insects. At this station the Creek is approximately six meters wide with a relatively fast flow rate.

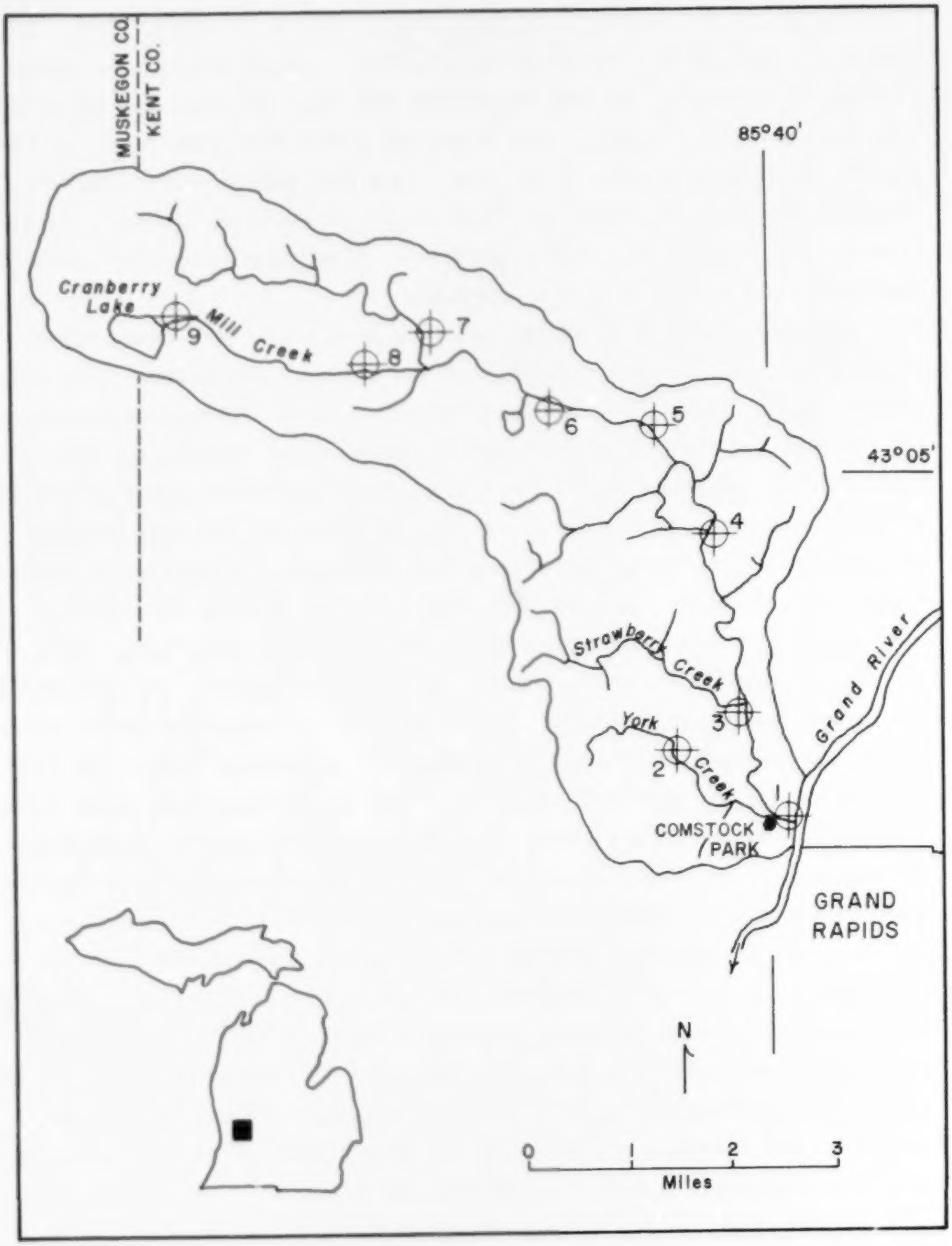
MUSKEGON CO.
KENT CO.
85°40'
43°05'
Cranberry Lake
Mill Creek
Strawberry Creek
York Creek
Grand River
COMSTOCK PARK
GRAND RAPIDS
1
2
3
4
5
6
7
8
9
N
0
1
2
3
Miles

Figure 13-1. Map of the nine permanent sampling stations established on Mill Creek.

Station 2 is located where York Creek crosses Lamarough Road. The bottom consists of fine sand and silt with a moderately high percentage of organic material. Aquatic vegetation was abundant with the Creek width between 0.9 and 1.2 meters. The organisms found were gastropods representing the Mollusks; Odonata, Hemiptera, and Coleoptera representing the insects; and Gasterosteidae and Cyprinidae representing Pisces. The flow rate at this station was moderately slow. Predominate organisms were the Gastropods which were found in abundance.

Station 3 is located at Stoney Creek Road where Strawberry Creek crosses it. The bottom material consists of sands and stones, with silt pockets along the banks in areas of low flow rate. Percentage of organic material is low at this station and the Creek width varies from 2.4 to 3.1 meters with a moderate flow rate. Some of the organisms found were gastropods representing the Mollusks, Isopods representing the Crustaceans, Salientians representing Amphibians, and Hemiptera and Coleoptera representing the insects. Isopods were found in abundance at this station.

Station 4 is located where Mill Creek crosses 7 Mile Road, which is a couple of hundred yards downstream of a golf course. At this station the bottom material is similar to station 3 except stones are more abundant. The percentage of organic material is moderately high. The flow rate is moderately fast and the Creek width is approximately three meters. Organisms found at this station were gastropods and pelecypods representing the Mollusks, Decapods representing the Crustaceans, Salientians representing the Amphibians, Cyprinidae representing Pisces, and Ephemeroptera, Trichoptera, Coleoptera, Hemiptera, Diptera representing the insects.

Station 5 is located where Mill Creek crosses M-37. Bottom material is rocky with pockets of sand. Organic content is moderately high and vegetation moderately abundant. The flow rate is moderately fast and the Creek is approximately three meters wide. Pelecypods and Gastropods represent the Mollusks and Decapods represent the Crustaceans. The insects are represented by Diptera, Coleoptera, Ephemeroptera, and Trichoptera.

Station 6 is a cove in the northwestern corner of Baumhoff Lake. Bottom consists of silt mixed with sand, which has been added. Aquatic vegetation is very abundant. Organisms found here are Gastropods representing Mollusca, Amphipods representing Crustaceans, Salientians representing Amphibians, Hirudinea representing the Annelids, and Coleoptera, Hemiptera, and Odonata representing the insects.

Station 7 is located at 9 Mile Road where a Mill Creek feeder stream crosses. Bottom material is stones and sand with beds of silt in areas of low flow rate. The stream is approximately 1.5 meters in width with moderate flow rate. Some of the organisms found here are pelecypods representing the Mollusks, Decapods representing the Crustaceans, Cyprinidae and Umbridae representing Pisces, and Hemiptera, Trichoptera, Ephemeroptera, Diptera and Coleoptera representing the insects.

Station 8 is located where Mill Creek crosses Peach Ridge Road. The bottom material is silt and sand, containing a high percentage of organic material. Creek flow rate at this station is approximately 1.5 meters. The organisms found were Gastropods representing Mollusca, Umbridae representing Pisces, and Hemiptera, Coleoptera, and Odonata representing the insects.

Station 9 is located on the north shore of Cranberry Lake. Bottom material is sand and silt with a relatively high percentage of organic material. No organisms were found at this station. In summer, water turned green by large populations of algae.

METHODS

Automated Sampling

The primary focus of this effort is on the understanding of the transport processes associated with pesticide movement from an agricultural watershed and an assessment of the role of precipitation on the transport of pesticides.

In an effort to assess the role that precipitation plays in the release and transport of pesticides into and through the stream; the efforts of the past two growing seasons (1975-76 and 1976-77) were to analyze water and sediment samples taken during precipitation events. Samples were taken every 770 seconds with eight such samples combined to give a composite sample with a volume of 3.8 ℓ. Twenty-eight composite samples were taken over a 48 hour period during which a hydrologic event occurred in Mill Creek.

An intensive monitoring system of hydrologic variables has been in operation on Mill Creek since August 1975. Stream discharge is continuously recorded at gauging stations located at the State Highway M-37 crossing of Mill Creek and on Mill Creek below the confluence with North Branch (see Figure 10-1, stations 5, 7, and 8). Estimates of flow at other stations are obtained by an indexing technique. Precipitation data are obtained from three recording gauges located in such a fashion that a representative average rainfall can be evaluated for the entire watershed. Other manual rain gauges are utilized to supplement and check the recording gauges.

Several water quality parameters are measured at various locations on the Mill Creek watershed, however, the parameter of concern in this study is pesticide concentration. The monitoring of pesticides is performed at three stations along the stream where discharge is simultaneously measured. Pesticide concentrations are available as (1) concentration of dissolved pesticide (5 μ size and below), and (2) concentration of pesticide on suspended solids (greater than 5 μ size).

Auxiliary Electronic Controller for the ISCO Water Sampler for Automated Collection

The auxiliary electronic controller was designed specifically to provide enhanced capabilities to ISCO Model 1392 samplers since ISCO samplers retrofitted with these auxiliary electronic controllers can be programmed more readily to acquire water quality samples on different parts of anticipated hydrographs. Sampling intervals are programmable, selectable in ten second increments from less than one minute to 2.7 hours. Two modes of operation are possible.

Mode 1: Sampling interval is constant for all 28 samples.

Mode 2: The first 16 samples are taken at the selected interval; subsequent samples are then taken at double this interval.

The sampling interval is selected by three thumbwheel switches; actual interval in seconds, is ten times the displayed value. Position of the toggle switch sets the mode. A momentary pushbutton switch and indicator light are provided for diagnostic purposes. When power is applied, the push-to-test switch will cause the indicator light to display the internal clock frequency (two cycles per second).

In normal operation, sample collection is to begin when power is applied to the ISCO sampler and installed auxiliary controller. When the power is turned on, the sampler will initialize itself and index the funnel one bottle position. The auxiliary controller allows 12 seconds to complete the funnel indexing, then commands the sampler to collect a sample. Samples are periodically taken from this point on at the interval and mode set by the controls. For example, if the "sample interval select" thumbwheel switches indicate 234, then samples will be taken at intervals of 2430 seconds, provided the controller is in Mode 1.

Sample Storage and Handling

The methods of sampling runoff were the manual collection of individual samples during snowmelt runoff, and the automatic and manual collection of samples during rainfall runoff. Composite samples for each pesticide group were then made from the individual samples. Each individual sample represented a certain percentage of the total flow, therefore the volume taken from the individual sample was this percentage multiplied by the required volume of the composite sample.

Discrete samples were held at 4 C prior to compositing. Compositing was completed within 12 to 28 hours after sample collection. Part of the composite sample was then frozen for later analysis. Laboratory determinations on the remaining sample portion were finished within one week of initial collection. Samples were stored at 4 C during this period. Passing the sample through the 5.0 micron filter allowed the determination of the soluble fraction pesticides.

Certain determinations were thought to be affected by freezing and these were conducted on fresh, unfrozen aliquots. All determinations, which were carried out on a sample which was preserved by freezing, were verified by utilizing a test set of samples to determine the concentration of the particular parameter before and after frozen storage.

Gas Liquid Chromatography for the Analysis of Organophosphate, Carbonate, S-Trizine, and Phenoxy Acid, and Chlorinated Hydrocarbon Pesticides

The methods are rather specific for a particular compound. All procedures that are being employed are published procedures, or those used by the company when registering the compound.

Confirmation of Residues by Mass Spectrometry

All samples from a given event for a given class of pesticides were pooled and then analyzed by GLC-MS-CPU. Identities were confirmed by comparisons of the samples' mass spectrum (11 masses with highest intensity) with mass spectra of standards in the computer library.

Quality Control

Samples have been routinely exchanged between the Michigan State University Pesticide Analytical Laboratory and the Pesticide Residue Laboratory of the Michigan Department of Agriculture. These two laboratories are also involved in interagency and interlaboratory (IR-4) quality control programs.

Pesticide Usage Survey

Since 1972, Michigan State University's Pesticide Research Center has been maintaining computerized records of actual pesticide use on a farm-by-farm basis within the watershed. Printouts such as shown in TABLE 13-1 are available for 90% of the farms in the basin. Other printouts such as shown in Figure 13-2 can be obtained on demand from the author.

RESULTS

The Mill Creek system is an intricate and interactive system directly related to discharge mechanisms. Our results show that as the flow rate increases (volume increases) the pesticide in the soluble fraction is diluted, but at the same time increased scouring of the land occurs carrying into the stream an increased burden of pesticides in the adsorbed state.

TABLE 13-1. TABULAR PRINTOUT OF PESTICIDE USE IN ONE FARM IN THE MILL CREEK BASIN

```
GROWER:
NYBLAD      H    IN KENT        COUNTY IN MICHIGAN

 1973
                                APPLES      -     15 ACRES



                                 AVERAGE          AVERAGE
PESTICIDE      X      APPS    ACRES SPRAYED       LBS/ACRE      PER CENT TREATED
               X
XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX
               X
CYGON          X        2           7               .07              100
ETHION         X        1          15               .25              100
GUTHION        X        4           7               .50              100
PB ARSNATE     X        8           7              2.09              100
PHSPHMIDON     X        2          11               .73              100
SEVIN          X        4           7              1.38              100
TEPP           X        2           7               .16              100
ZOLONE         X        2           7              1.20              100
KARATHANE      X        4           7               .52              100
PLICTRAN       X        2           7               .38              100
SUPER. OIL     X        1          15             55.44              100
CAPTAN         X       23           8              1.90              100
CYPREX         X        4          13               .95              100
SULFUR         X        4           7              2.85              100
```

```
KENT        COUNTY IN MICHIGAN
     GUTHION     USE ON APPLES
                I
                I
                I
                I
                I
           3.00 I
                I
                I
                I
                I
                I
                I
                I
           2.00 I                                X
                I                                X
                I                                X
                I                                X
                I                                X
                I                                X
                I                                X
                I                                X
           1.00 I                                X
                I                                X              X
                I                                X    X   X     X
                I                            XX  X    XX  X X   X      X   X
                I                            XXXXX  X XXX XXX   X   X XXX  X
                I                            XXXXXXXXXXXXXXXX   X   X XXX  X
                I                            XXXXXXXXXXXXXXXXX XX   X XXX  X
                I                            XXXXXXXXXXXXXXXXX XX   X XXX  X
                -------------------------------------------------------------------------------------
                     MAR       APR       MAY       JUN       JUL       AUG        SEPT       OCT
```

Figure 13-2. Graphic printout example of application rates and seasonal distribution of application for Guthion in the Mill Creek watershed (1976). Values in lbs/acre.

Pesticides that were found are Simazine, Atrazine, p,p'-DDT, p,p'-DDD, p,p'-DDE, Aldrin, Dieldrin, and Guthion. The data suggest that the relative concentration of pesticide in water as to that in the suspended matter is related to the individual pesticide. In general, the highest concentrations are found at the beginning of a precipitation event (Figures 13-3, 13-4, and 13-5).

It is to be noted that of the 59 pesticides analyzed for TABLE 13-2, the major pesticides found are still the chlorinated hydrocarbons and Atrazine, Simazine and Guthion. The only organophosphate found was Guthion. TABLES 13-3 through 13-7 give the summaries for the data collected from the three automated sampling stations for 1976 and 1977. TABLES 13-3 and 13-4 show that the suspended material (filtered pesticides) is always consistently higher than the dissolved pesticide content of the stream. These two tables also indicate that the descending hydrograph of an event carries the greater burden of pesticide residue. The movement of pesticide off the land into the stream lags behind the onset of any precipitation event. TABLES 13-5 through 13-7 summarize the loading at the automated sampling sites. It must be remembered that all data are based on relatively few events since the summers of 1976 and 1977 were extremely dry with few good precipitation events.

DISCUSSION

Any pesticide ecosystem involves many interactions. The Mill Creek watershed is mainly an orchard ecosystem. The pesticide-orchard ecosystem model consists of two parts, the orchard model and the stream transport model.

The Orchard Model

The orchard model simulates pesticide dynamics between compartments in the orchard. The model requires exogenous inputs of spray rate (kg/ha), spray schedule, mowing schedule, tree state, rainfall amount, rainfall derivation, rainfall intensity and timing of rainfall events; and outputs daily pesticide magnitudes ($\mu g/cm^2$) for each compartment.

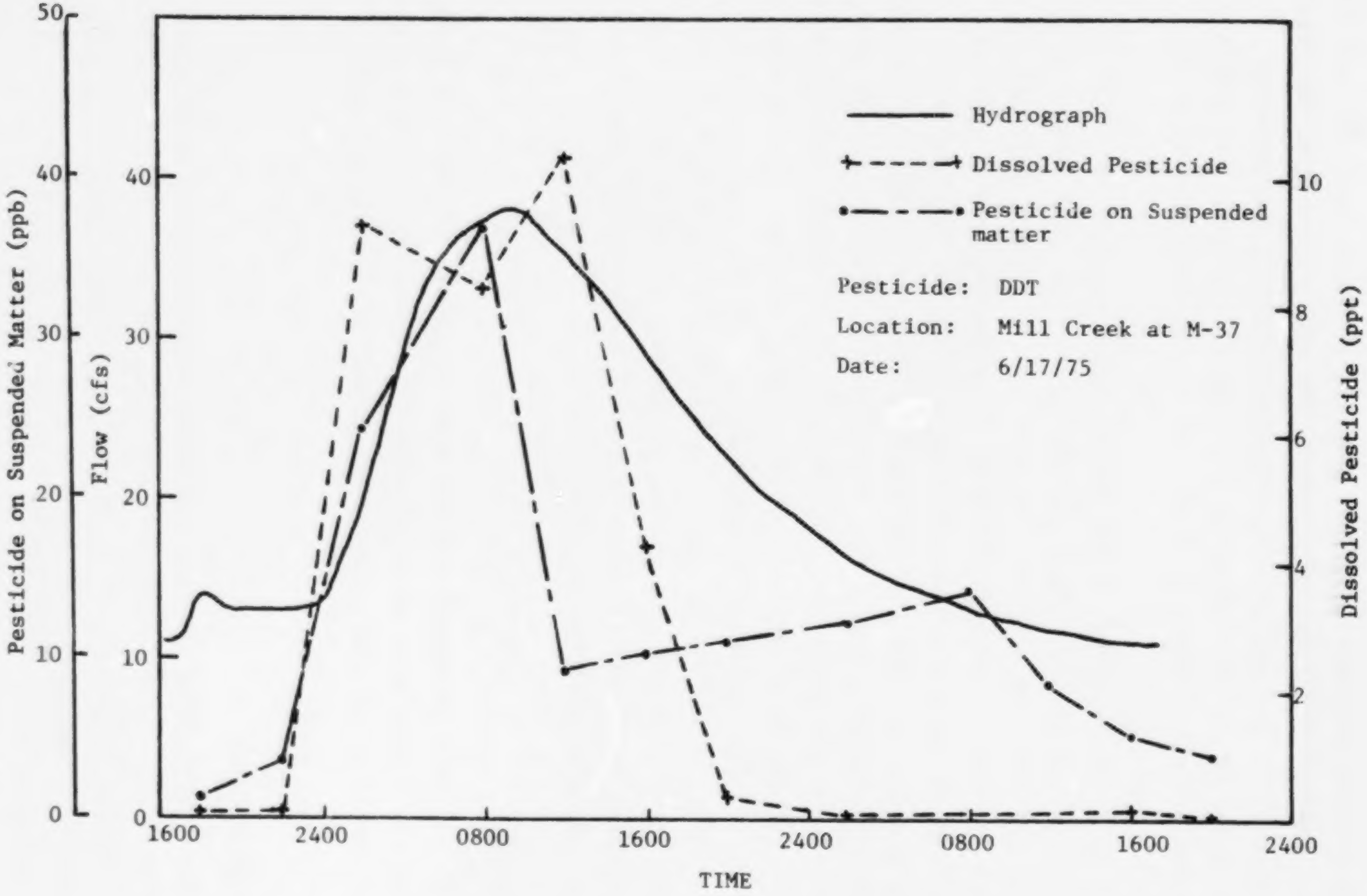

Figure 13-3. Variation of pesticide concentration and flow rate over a hydrologic event (ppb = parts per billion, ppt = parts per trillion).

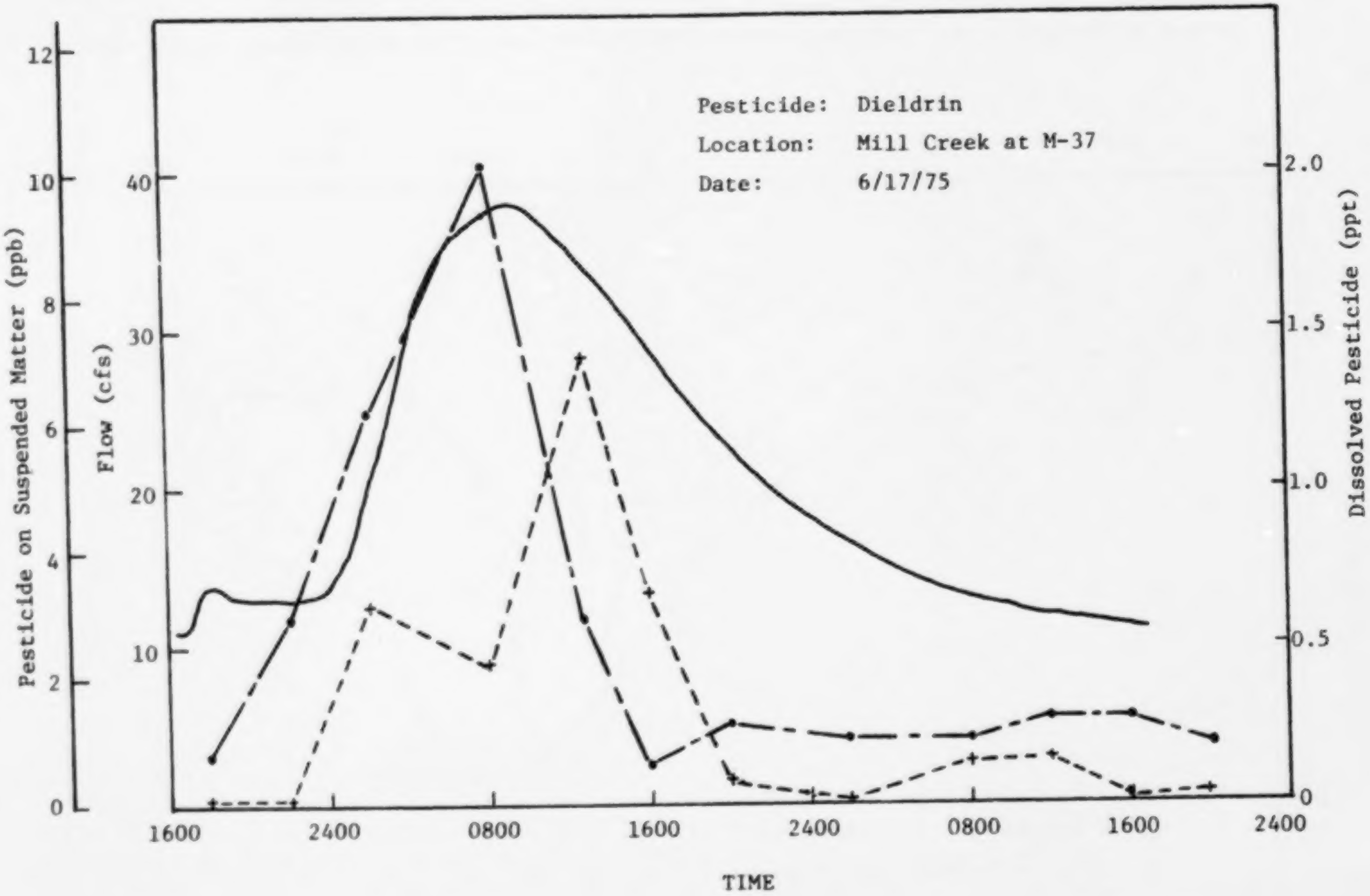

Figure 13-4. Variation of pesticide concentration and flow rate over a hydrologic event. (See Figure 13-3 for the legend.) (ppb = parts per billion, ppt = parts per trillion)

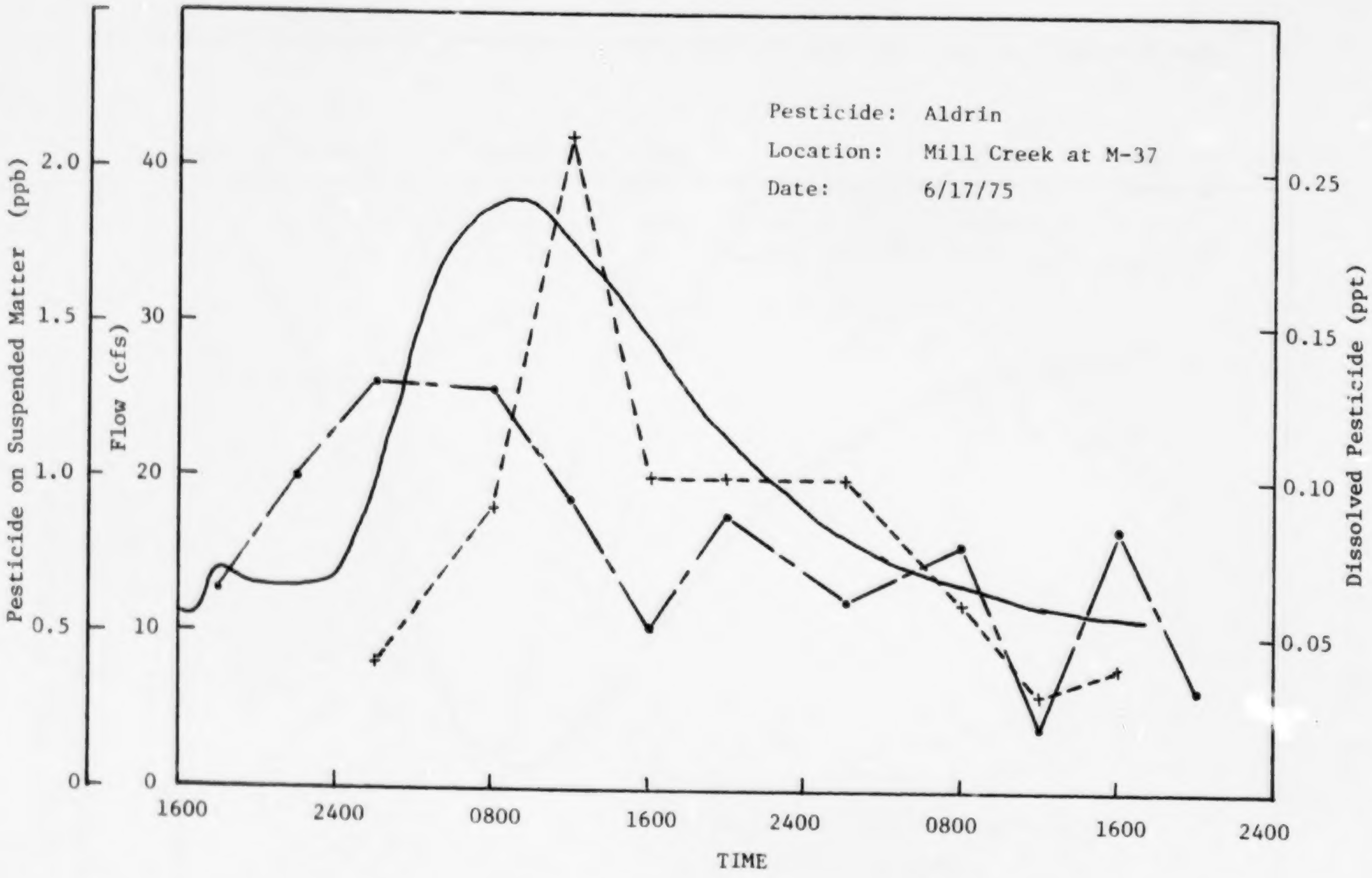

Figure 13-5. Variation of pesticide concentration and flow rate over a hydrologic event. (See Figure 13-3 for the legend.) (ppb = parts per billion, ppt = parts per trillion)

TABLE 13-2. PESTICIDES ANALYZED FOR IN THE MILL CREEK WATERSHED

Aldicarb
Aldrin
Atrazine
Benomyl
Binopacryl
Bromacil
Cacodylic Acid
Captan
Chlordimeform
Chloropropylate
2,4-D
DDD-p,p'
DDE-p,p'
DDT-p,p'
Diazinon
Dichlone
Demeton-O
Demeton-S
Dieldrin
Diphenamide
Dinocap
Dodine
Endosulfan I
Endosulfan II
Endrin
Ethion
Fenthion
Ferbam
Fundal
Gardona
Glyodin
Guthion
Heptachlor
Heptachlor epoxide
Hexachlorobenzene
Imidan
Isodrin
Kelthane
Lannate
Lindane
Malathion
Methyl parathion
Methoxychlor
Mevinphos
Omite
Paraquat
Parathion
PCNB
Phosphamidon
Plictran
Sevin
Silvex
Simazine
Systox
2,4,5-T
Tepp
Thiram
Trifluralin
Zineb

TABLE 13-3. PESTICIDE EXPORTS FROM THE 3058 ha MILL CREEK WATERSHED, 1975-76 WATER YEAR*

Pesticide	---------EVENT FLOWS ---------				
	Rising Hydrograph (kg)	Descending Hydrograph (kg)	Non-Event Flows (kg)	Total Exports (kg)	Unit Area Loads (kg/ha)
		DISSOLVED PESTICIDES			
DDT	0.500 ± .0002	15.427 ± .013	ND**	--	--
DDE	0.361 ± .0001	13.228 ± .012	ND	--	--
DDD	0.029 ± .00001	1.063 ± .001	ND	--	--
Aldrin	0.043 ± .00001	1.159 ± .001	ND	--	--
Dieldrin	0.083 ± .00003	2.669 ± .004	ND	--	--
Guthion	0.079 ± .00003	0.688 ± .002	ND	--	--
Atrazine	1.933 ± .0006	39.247 ± .124	ND	--	--
Simazine	0.174 ± .0001	2.898 ± .005	ND	--	
		FILTERED PESTICIDES			
DDT	4.859 ± .002	281.440 ± .09	13.859 ± 0.00	300.160 ± 0.09	0.0982
DDE	5.214 ± .003	196.550 ± .13	12.573 ± 0.00	214.340 ± 0.13	0.0701
DDD	0.474 ± .0002	17.420 ± .017	1.500 ± 0.00	19.394 ± 0.017	0.0063
Aldrin	0.526 ± .0002	1.570 ± .002	1.786 ± 0.00	3.882 ± 0.002	0.0013
Dieldrin	0.696 ± .0003	17.107 ± .024	3.429 ± 0.00	21.232 ± 0.024	0.0069
Guthion	0.451 ± .0002	6.612 ± .018	ND	--	--
Atrazine	13.807 ± .005	283.030 ± .85	ND	--	--
Simazine	3.307 ± .001	50.644 ± .172	ND	--	--

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* There was 3.6 times more runoff in the 1975-76 Water Year than in the 1976-77 Water Year.

** ND indicates no data.

TABLE 13-4. PESTICIDE EXPORTS FROM THE 3058 ha MILL CREEK WATERSHED, 1976-77 WATER YEAR*

Pesticide	---------EVENT FLOWS --------- Rising Hydrograph (kg)	Descending Hydrograph (kg)	Non-Event Flows (kg)	Total Exports (kg)	Unit Area Loads (kg/ha)
			DISSOLVED PESTICIDES		
DDT	1.852 ± .001	3.430 ± .036	0.433 ± 7.104	5.715 ± 7.104	0.00187
DDE	2.284 ± .002	3.411 ± .074	0.303 ± 1.245	5.998 ± 1.247	0.00196
DDD	0.097 ± .0001	0.178 ± .006	0.026 ± 0.000	0.301 ± 0.006	0.00010
Aldrin	0.113 ± .0001	0.156 ± .005	0.129 ± 0.553	0.398 ± 0.553	0.00013
Dieldrin	0.244 ± .0001	0.279 ± .014	0.047 ± 0.276	0.570 ± 0.276	0.00019
Guthion	0.007 ± .000004	0.026 ± .00002	0.031 ± 0.232	0.064 ± 0.232	0.00002
Atrazine	0.791 ± .001	1.230 ± .095	0.563 ± 12.865	2.584 ± 12.865	0.00084
Simazine	0.036 ± .00002	0.052 ± .004	0.144 ± 4.140	0.232 ± 4.140	0.00008
			FILTERED PESTICIDES		
DDT	24.136 ± .020	58.413 ± 0.647	3.001 ± 5.201	85.550 ± 5.241	0.0280
DDE	33.261 ± .028	55.811 ± 1.261	2.732 ± 10.424	91.804 ± 10.500	0.0300
DDD	1.015 ± .001	2.888 ± 0.102	0.209 ± 1.674	4.112 ± 1.677	0.0013
Aldrin	0.945 ± .001	1.583 ± 0.067	0.182 ± 1.239	2.710 ± 1.241	0.0009
Dieldrin	1.912 ± .001	4.418 ± 0.235	0.377 ± 2.841	6.707 ± 2.851	0.0022
Guthion	0.151 ± .0001	0.697 ± 0.447	0.510 ± 2.600	1.358 ± 2.638	0.0004
Atrazine	7.152 ± .005	10.433 ± 0.675	5.537 ± 42.580	23.122 ± 42.585	0.0076
Simazine	0.706 ± .001	0.752 ± 0.061	1.486 ± 22.590	2.944 ± 22.590	0.0010

---

* There was 3.6 times more runoff in the 1975-76 Water Year than in the 1976-77 Water Year.

TABLE 13-5. FLOW WEIGHTED MEAN CONCENTRATIONS (μg/ℓ) OF PESTICIDES EXPORTED FROM THE 3058 ha MILL CREEK WATERSHED

		----- EVENT FLOWS ------		
	Pesticide	Rising Hydrograph	Descending Hydrograph	Non-Event Flows
		1975-76 WATER YEAR*		
DISSOLVED PESTICIDES	DDT	0.531	4.166	ND**
	DDE	0.366	3.572	ND
	DDD	0.052	0.287	ND
	Aldrin	0.094	0.313	ND
	Dieldrin	0.097	0.721	ND
	Guthion	0.112	0.186	ND
	Atrazine	2.245	10.598	ND
	Simazine	0.201	0.782	ND
FILTERED PESTICIDES	DDT	5.192	75.998	1.940
	DDE	5.341	53.075	1.760
	DDD	0.799	4.704	0.210
	Aldrin	0.738	0.424	0.250
	Dieldrin	0.884	4.619	0.480
	Guthion	0.535	1.785	ND
	Atrazine	16.327	76.428	ND
	Simazine	3.828	13.676	ND
		1976-77 WATER YEAR*		
DISSOLVED PESTICIDES	DDT	1.201	13.727	0.170
	DDE	1.280	15.885	0.119
	DDD	0.045	0.640	0.010
	Aldrin	0.093	0.501	0.050
	Dieldrin	0.122	1.063	0.018
	Guthion	0.014	0.351	0.012
	Atrazine	1.198	6.862	0.221
	Simazine	0.071	0.725	0.056
FILTERED PESTICIDES	DDT	1.323	19.831	1.176
	DDE	1.232	18.769	1.071
	DDD	0.070	1.053	0.082
	Aldrin	0.083	0.585	0.072
	Dieldrin	0.113	1.559	0.148
	Guthion	0.020	0.498	0.200
	Atrazine	0.753	5.624	2.170
	Simazine	0.027	0.408	0.582

* There was 3.6 times more runoff in the 1975-76 Water Year than in the 1976-77 Water Year

** ND indicates no data.

TABLE 13-6. STREAM EXPORT OF PESTICIDES FROM THE 1146 ha MILL CREEK WATERSHED ABOVE THE CONFLUENCE WITH NORTH BRANCH

	Pesticide	Flow Weighted Mean Concentration (μg/ℓ)	Total Load (kg)	Unit Area Loads (kg/ha)
		1975-76 WATER YEAR		
DISSOLVED	DDT	1.167	2.635 ± 386.958	0.0023
	DDE	0.740	1.671 ± 242.016	0.0015
	DDD	0.073	0.166 ± 11.892	0.00014
	Aldrin	0.073	0.165 ± 6.516	0.00014
	Dieldrin	0.154	0.347 ± 32.180	0.00030
	Guthion	0.046	0.105 ± 9.241	0.00009
	Atrazine	3.448	7.787 ± 1599.1	0.0068
	Simazine	0.243	0.549 ± 29.428	0.00048
FILTERED	DDT	17.480	39.48 ± 6,500	0.0345
	DDE	11.530	26.04 ± 4,152	0.0227
	DDD	1.030	2.33 ± 226	0.0020
	Aldrin	0.985	2.23 ± 321	0.0020
	Dieldrin	2.356	5.32 ± 726	0.0046
	Guthion	0.564	1.28 ± 157	0.0011
	Atrazine	27.122	61.26 ± 12,239	0.0535
	Simazine	5.173	11.68 ± 2,305	0.0102
		1976-77 WATER YEAR		
DISSOLVED	DDT	0.666	0.330 ± 3.01	0.00029
	DDE	0.522	0.260 ± 0.85	0.00023
	DDD	0.023	0.011 ± 0.067	0.00001
	Aldrin	0.052	0.026 ± 0.041	0.00002
	Dieldrin	0.058	0.029 ± 0.146	0.00003
	Guthion	0.010	0.005 ± 0.000	0.000004
	Atrazine	0.483	0.238 ± 0.907	0.00021
	Simazine	0.014	0.007 ± 0.002	0.000006
FILTERED	DDT	5.293	2.609 ± 11.863	0.0023
	DDE	4.156	2.049 ± 10.980	0.0018
	DDD	0.198	0.098 ± 1.091	0.00009
	Aldrin	0.194	0.096 ± 0.845	0.00008
	Dieldrin	0.505	0.249 ± 1.630	0.00022
	Guthion	0.218	0.107 ± 0.320	0.00009
	Atrazine	4.053	1.998 ± 4.381	0.0017
	Simazine	0.231	0.114 ± 0.158	0.00010

TABLE 13-7. STREAM EXPORT OF PESTICIDES FROM THE 889 ha NORTH BRANCH SUBWATERSHED OF MILL CREEK

	Pesticide	Flow Weighted Mean Concentration (μg/ℓ)	Total Load (kg)	Unit Area Loads (kg/ha)
		1975-76	WATER YEAR	
DISSOLVED	DDT	0.994	1.953 ± 286	0.0022
	DDE	0.786	1.545 ± 174	0.0017
	DDD	0.068	0.133 ± 17.5	0.00015
	Aldrin	0.153	0.301 ± 37.9	0.00034
	Dieldrin	0.195	0.384 ± 63.9	0.00043
	Guthion	0.047	0.093 ± 10.27	0.00010
	Atrazine	3.892	7.653 ± 1,247	0.0086
	Simazine	0.305	0.600 ± 26.91	0.00067
FILTERED	DDT	15.680	30.84 ± 4,813	0.0347
	DDE	10.813	21.26 ± 2,877	0.0239
	DDD	1.247	2.45 ± 286	0.0028
	Aldrin	0.925	1.82 ± 223	0.0021
	Dieldrin	2.017	3.966 ± 520	0.0045
	Guthion	0.582	1.145 ± 144	0.0013
	Atrazine	28.993	57.02 ± 8,646	0.0641
	Simazine	5.580	10.97 ± 1,773	0.0123
		1976-77	WATER YEAR	
DISSOLVED	DDT	0.689	0.304 ± 6.301	0.00034
	DDE	0.695	0.306 ± 10.496	0.00034
	DDD	0.021	0.009 ± 0.104	0.00001
	Aldrin	0.068	0.030 ± 0.708	0.00003
	Dieldrin	0.071	0.031 ± 0.469	0.00003
	Guthion	0.011	0.005 ± 0.026	0.000006
	Atrazine	0.417	0.184 ± 1.304	0.00021
	Simazine	0.018	0.008 ± 0.017	0.000009
FILTERED	DDT	8.028	3.541 ± 110	0.0040
	DDE	7.456	3.290 ± 88	0.0037
	DDD	0.376	0.166 ± 2.21	0.00019
	Aldrin	0.311	0.137 ± 3.94	0.00015
	Dieldrin	0.847	0.374 ± 7.85	0.00042
	Guthion	0.194	0.086 0.572	0.00010
	Atrazine	3.860	1.703 ± 11.23	0.0019
	Simazine	0.268	0.118 ± 0.681	0.00013

The conceptual model of the orchard consists of 15 compartments from three horizontal regions (trunk, canopy and alley), four to five vertical strata (leaves, grass litter, moss, soil), and a runoff sink. The trunk region represents a cylinder with a height equal to the height of the tree and a diameter incorporating the tree trunk and a small neighborhood around the trunk. The canopy region depicts a cylinder whose outer boundary corresponds to the tree crown and inner boundary touches the trunk cylinder. The alley region is everything not present in either the trunk or canopy regions. Each region contains at least four strata: grass, litter, moss, and soil; and the trunk and canopy region contains the leaf stratum as well. Each vertical stratum is assumed to have a uniform dispersion throughout each region.

Pesticide Application--

When spraying occurs, the amount of pesticide reaching each orchard compartment is a function of the amount of pesticide applied, spraying technique, local weather conditions, percentage of orchard ground surface covered by tree canopies and degree of fullness for the average tree. The amount of pesticide applied to the orchard is recorded as kg/ha. The percentage of ground surface covered by the trees' canopy and degree of fullness of the average tree is measured by a pesticide interception potential. The interception potential varies from zero, representing a dormant orchard with a low tree density, to one, depicting a very dense orchard with healthy, full trees. The interceptional potential varies during the growing season to reach a maximum value at approximately harvest time; the maximum value is orchard specific. The relationship between the pesticide distribution and interception potential was modeled by a truncated Maclaurin series expansion; represented for the i^{th} compartment as

$$A_i = a_i + b_i X$$

where A_i is the proportion of pesticide intercepted by the i^{th} compartment,

a_i is a distribution constant,

b_i represents the change in pesticide allocation to the i^{th} compartment as a function of the change in interception potential, and X is the interception potential.

It should be noted that a_i and b_i are dependent on the spraying technique employed.

Local weather conditions are assumed to have an insiginficant effect on the spray distribution since spraying only took place under favorable weather conditions.

The amount of pesticide to be added to the i^{th} compartment then becomes

$$y_i = [a_i + b_i X]S$$

where a_i, b_i, and X are defined above,

S is the spray rate (kg/ha),

and y_i is the amount of applied pesticide that reaches the i^{th} compartment.

Pesticide Attenuation--

Pesticide attenuation is the process in which microbial degradation, photochemical degradation, volatilization, chemical degradation and invertebrate accumulation and degradation remove pesticide from the orchard ecosystems. Accurate prediction of attenuation losses must therefore delineate the relationships between these attenuation mechanisms and the environmental conditions which regulate each mechanism.

Field tests have shown that microbial degradation of parathion may be directly dependent on soil pH and organic matter and soil moisture and temperature; however, physicochemical characteristics of soil, such as its adsorption properties, protect atrazine and diquat molecules from microbial attack. Photochemical degradation of atrazine and azinphosmethyl occur when subjected to light of wave-length 253.7 nm. Volatilization of pesticide is dependent on its vapor pressure, moisture, temperature, and degree of adsorption. Invertebrate accumulation and degradation of pesticides depends on the environmental parameters such as air and soil temperature, soil moisture, and soil organic content which controls a species' physiological development, metabolic rate, survival and reproduction. Chemical degradation of diazinon and atrazine is adsorption catalyzed; that is, as the degree of adsorption to soil particles increases, chemical hydrolysis and thus degradation increase. The degree of adsorption is, in turn, affected by type of soil colloid, pH, temperature, moisture and organic matter.

Consequently, the final predictive form of the pesticide attenuation submodel must consider air and soil temperatures, soil moisture, soil organic content, soil pH, solar illumination, and the vapor pressure of the given pesticide in order to accurately estimate pesticide losses.

Presently, the functional relationships between pesticide attenuation and the environmental variables have not been elucidated, so pesticide attenuation is temporarily modeled by combining all the attenuation mechanisms into a constant first order degradation rate. By calculating a degradation rate for each compartment, a portion of the variation in the environmental variables between compartments can be accounted for, although seasonal dynamics cannot.

The present attenuation equation for the i^{th} compartment is:

$$P_i' = P_i(1-d_i)$$

where P_i' and P_i are the amount of pesticide present at time T+1 and T, respectively,

and d_i is the compartment-specific attenuation rate.

Physical Alteration--

Farming techniques (disking, pruning, mowing, irrigation) alter the physical structure of orchards and thus alter pesticide dynamics. Since pruning occurs during the winter and since the study focuses its attention on pesticide dynamics during the growing season, pruning is not considered. Irrigation is not applicable to Michigan orchards since rain provides sufficient moisture. Disking is used in some Michigan orchards to control rodents and undesirable vegetation; however, disking is not used in the orchard field experiments and is not considered in the model. The principal method used to control grass is mowing; which results in moving pesticide from the grass to the litter. The amount of pesticide moved from the i^{th} grass compartment to the j^{th} litter compartment is modeled by:

$$C_i = (P_i)(M)$$

where C_j is the amount of pesticide moved,

P_i is the amount of pesticide present in the i^{th} grass compartment,

and M is the proportion of pesticide moved during a single mowing event.

Climatic Data--

Several climatic variables are very important in determining the fate and impact of pesticides on apple orchards. These include amount of rainfall, intensity of rainfall, duration of rainfall, and soil temperature.

The intensity of rainfall is assumed to be the primary driving mechanism for moving pesticide between vertical strata. The intensity, magnitude and duration of rainfall principally determine soil saturation and runoff. Soil temperature and soil moisture as stated are instrumental in determining pesticide attenuation.

Amount of rainfall, rainfall intensity, and duration of rain activity are inputed directly into the model on a rainfall event basis. Daily minimum and maximum air temperatures, collected approximately ten miles from the experimental site, are inputed and converted into minimum and maximum soil temperatures by Fourier transforms.

Movement in Soil--

Pesticide mobility in soil results from the interaction of soil particle adsorption-desorption, chemical reaction, pesticide solubilities, water flux, and the physical properties of the soil. However, the movement of azinphosmethyl within the soil profile can be principally explained as a negative relationship to field moisture capacity. This relationship suggests that azinphosmethyl is strongly held to soil particles. Consequently, azinphosmethyl mobility within the soil is very low; thus, pesticide mobility is assumed to have an insignificant contribution to pesticide dynamics and is not modeled. As new pesticides are added to the orchard model, the importance of soil mobility will be reevaluated.

Vertical Movement--

During a rain event pesticide moves vertically from the higher orchard compartments toward the lower in each region. The proportion moving is a function of the degree of canopy fullness and intensity of rainfall.

Rainfall intensities are classified into one of three intensity categories -- light, moderate, or heavy, from which unique E and F matrices are determined for each intensity class.

The degree of canopy fullness, "tree state," depicts the obstruction to rainfall created by the average tree within the orchard. The value assigned to the tree state ranges from zero to one, with zero representing a condition where only dormant trees are present and one representing a very large, full tree such that the alley is almost completely obscured. The relationship between tree state and proportion of pesticide is modeled by a truncated Maclaurin series expansion.

The model for the vertical movement matrix representing the proportion of pesticide moving vertically from the i^{th} compartment to the j^{th} compartment in response to a rainfall of intensity class k is

$$V_{ij} = E_{ijk} + (F_{ijk})(t_s)$$

where t_s represents the tree state of the average tree within the orchard,

E_{ijk} is the vertical movement proportions when the tree state is zero,

F_{ijk} accounts for change in proportion of movement corresponding to any change in tree state,

and V_{ij} is the proportion of pesticide moving from compartment i to j.

The effect of rainfall intensities on pesticide movement is, therefore, modeled as a discrete approximation; while, the degree of canopy fullness provides a continuous measure.

To describe tree state, the maximum value of tree state or the tree state present just preceding harvest is inputed during model initialization.

Lateral Movement--

During a runoff event pesticide is redistributed within the soil region of an orchard, but more importantly runoff provides a mechanism for the pesticide to leave the orchard. Runoff provides the driving mechanism for lateral redistribution of pesticide. Consequently, to predict the amount of pesticide lost, runoff and the amount of pesticide coupled to runoff must be modeled.

Runoff was modeled on a single rainfall event basis by utilizing a modified rational method to predict the rate of runoff:

$$R = (C)(I)(A)$$

where R represents the greatest runoff rate occuring for a single rainfall event,

C is a function of the orchard surface characteristics and the amount of rainfall from the storm being considered,

I is the average intensity of rainfall,

and A represents the area of the watershed.

Presently, the modified rational method provides a crude but adequate estimate of the rate of runoff. If greater accuracy and precision is desired in predicting runoff, other runoff models such as the ARM could be coupled directly.

The mechanism which couples pesticide movement to runoff rate must describe the relationship between runoff and the desorption of pesticide from soil particles, the dissolution of stationary pesticide particles, the scouring and transport of soil particles on which pesticide is adsorbed and the diffusion of dissolved pesticide from the soil interstices. The coupling mechanism is assumed to be a function of runoff and is defined as:

$$PR_{.m} = 1 - e^{-A_j R}$$

where $PR_{.m}$ represents the proportion of pesticide removed from the m^{th} compartment,

R is the runoff rate,

and A_j is a coefficient describing the availability of pesticide to runoff coupling process for the j^{th} compartment.

This equation also produces a crude but adequate mechanism for pesticide uptake by runoff. If greater precision is desired, alternative coupling mechanisms can be implemented.

Runoff over the orchard is assumed to be uniform so the proportion of pesticide removed from the m^{th} vertical stratum is equivalent for all regions

$$PR_{1,m} = PR_{2,m} = PR_{3,m}$$

The proportion of pesticide removed from a given region is then redistributed into the soil stratum of the other regions or lost into the drainage area according to a proportion defined by the relative length of edge between adjacent regions.

The coupling equation generates a proportion which characterizes the redistribution of pesticide from the m^{th} vertical stratum in the n^{th} region to the soil stratum in the n^{th} region based on runoff rate. These proportions are then multiplied by the amount of pesticide present in each compartment to provide a measure of pesticide lateral movement.

$$P'_{n',soil} = \sum_{n=1}^{3} \sum_{m=1}^{5} PR_{n,m} \times P_{n,m} \qquad n' = 1,2,3$$

where $PR_{n,m}$ is the proportion of pesticide removed by runoff,

$P_{n,m}$ represents the amount of pesticide present before runoff,

and $P'_{n',soil}$ is the amount of pesticide moved into soil region n' after runoff.

Transport Model

As can be seen from the results section the adsorption of pesticides on particulate matter is extremely important in the Mill Creek watershed. Unlike other substances, such as inorganic ions (phosphates, nitrates) which readily dissolve, pesticides either emulsify, precipitate, or have a low solubility and remain in colloidal form or adsorb to particulate matter.

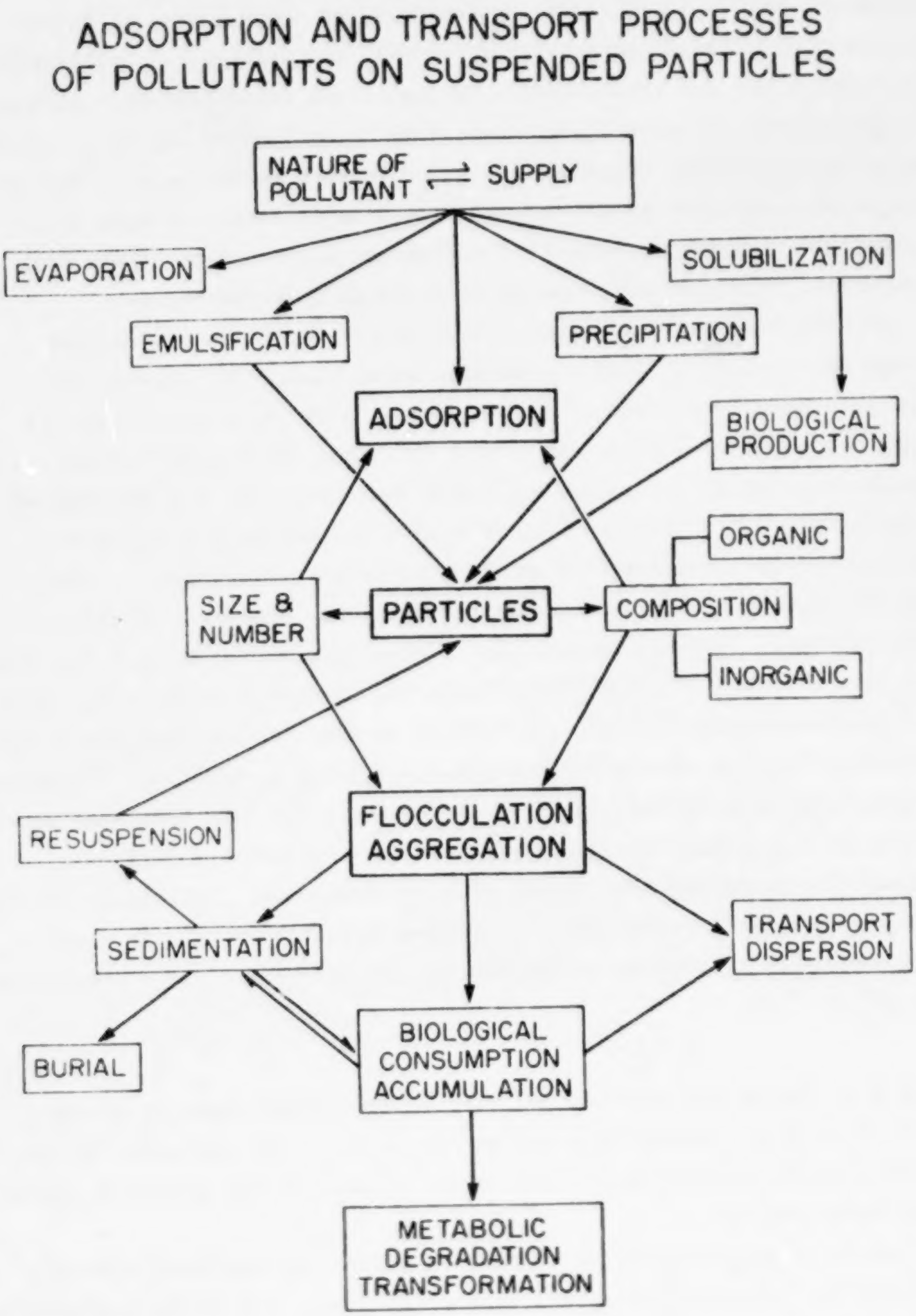
Association of pollutants with particulate matter in water greatly alters their subsequent fate. Compounds in solution are only available for uptake by organisms by absorption through membranes. Once precipitated or adsorbed, however, ingestion of concentrated amounts becomes possible. Also dispersal then follows sedimentation patterns of natural suspended material and the behavior of non-soluble pollutants becomes directly related to the dynamics of naturally occurring particles.

When a compound is added to water, it will either dissolve and enter into true solution, or remain insoluble and form a colloidal or particulate suspension. The initial state which a pollutant assumes determines its subsequent fate (Figure 13-6). Compounds of low solubility such as hydrophobic pesticides may be solubilized to some extent by association with surface active humic-like organic matter. Such compounds usually form emulsions. Also if concentrations approach or exceed compound solubility, accumulation occurs at the air-water interface where evaporation occurs. Chlorinated pesticides show this behavior and empirical equations have been derived to calculate potential evaporation rates for hydrocarbons of known vapor pressure and solubility.

Pesticides which do not dissolve become an integral part of the total suspended material and flocculate in a manner similar to naturally occurring suspended particles.

Pollutants like radionuclides and nutrients which dissolve or like hydrocarbon pesticides which form colloidal suspensions have apparent solubilities which are greatly affected by adsorption-desorption reactions with suspended particulate matter. Studies have indicated that suspended solids and colloidal gels can rapidly adsorb nutrients like phosphate. It has been demonstrated that equilibrium concentrations between individual sediment particles and water are reached quickly. Uptake to saturation levels, which varied inversely with particle size, was largely complete within 10 minutes, 50% of maximum values being reached after one minute. Desorption rates were slower. Desorption stabilized after an hour but final equilibrium concentrations were different for different pesticides.

Adsorption-desorption processes also greatly affect the distribution of organic hydrocarbons in water. The hydrophobic nature of many of these


ADSORPTION AND TRANSPORT PROCESSES OF POLLUTANTS ON SUSPENDED PARTICLES

NATURE OF POLLUTANT ⇌ SUPPLY
EVAPORATION
SOLUBILIZATION
EMULSIFICATION
PRECIPITATION
ADSORPTION
BIOLOGICAL PRODUCTION
ORGANIC
SIZE & NUMBER
PARTICLES
COMPOSITION
INORGANIC
RESUSPENSION
FLOCCULATION AGGREGATION
SEDIMENTATION
TRANSPORT DISPERSION
BURIAL
BIOLOGICAL CONSUMPTION ACCUMULATION
METABOLIC DEGRADATION TRANSFORMATION

Figure 13-6. Schematic outline of major processes which affect adsorption and transport of nonsoluble pollutants in water.

substances results in colloidal suspensions and accumulation at interfaces making determinations of true solubilities difficult. Qualitative and quantitative differences exist in pesticides associated with various size classes of microparticulate matter in natural water and it is possible that most hydrophobic compounds are bound to such particles. It has been pointed out that most particulate surface area in natural waters is accounted for by suspended matter $< 2\ \mu$ diameter and it seems likely that hydrophobic compounds will usually be bound to these particles.

Adsorption-desorption processes of pesticides in soil have been extensively reviewed. Particle surface area, charge and organic content determine adsorptive capacity in conjunction with water solubility and charge distribution. Researchers have indicated the extensive adsorptive capacity of clay particles and colloidal humic material for chlorinated hydrocarbons. Adsorption to suspended clay and sediment occurred by physical adsorption-desorption equilibria whereas adsorption to humic acid occurred by lipophilic binding and capillary adsorption within the humic polymer. Physical rather than chemical adsorption through the formation of weak hydrogen bonds appear to be the primary mechanism for uptake.

Numerous empirical plots can be used to describe adsorbed concentrations as a function of the concentration remaining in solution. Compounds of relatively high solubility (like nitrophenol) may form saturated monolayers, so that uptake becomes asymptotic above certain concentrations. Langmuir isotherms describe uptake of these compounds. Adsorption of less soluble compounds, present below saturation levels, however, is usually logarithmically related to concentration, and uptake follows a Freundlich plot

$$X = K\ C^n \tag{1}$$

where X is the amount adsorbed per unit weight of adsorbent, C is the equilibrium concentration in solution, and n and K are constants (slope and intercept) which represent the extent (capacity) and nature of adsorption, respectively.

Uptake from dilute concentrations of DDT by various particles was described by Freundlich isotherms with $n = 1$. Data for uptake experiments show a similar slope constant. The experiments were repeated using various particles exposed to lindane, aldrin and dieldrin. The slope constants for Freundlich plots were between 0.80 and 1.70 with a mean value (1.04) similar to published values derived for other compounds. This indicates physical binding with absolute values of n determined by the degree of competition of solvent for sites on the adsorbing surface.

Values of K are an indirect measure of the extent of adsorption. Increased temperature results in decreased values of K indicating the exothermic nature of adsorption which may be proportional to relative free energy changes. K values are also inversely related to particle diameter by the equation

$$K = a\ d^{-b} \tag{2}$$

where D is the spherical equivalent of particle diameter (μ) and a and b are constants. Organic matter in lake sediment and soil is a major determinant for adsorption of non-ionic pesticides. The importance of organic content is further substantiated by a reduction of marine sediment adsorption capacity for DDT by removal of humic material. Similarly, DDT uptake by sediment of various grain sizes was reduced an order of magnitude after ashing.

These observations suggest that a general expression for equilibrium concentrations of hydrophobic compounds on particles of various sizes may be of the form

$$X = \frac{C^n}{AD^b} \tag{3}$$

by combining equations (1) and (2). Further expansion to standardize for an effect of organic content on adsorption would be to express uptake per unit organic carbon (or a related index of organic material). Thus,

$$\frac{X}{c} = \frac{C^n}{a\ D^{\ b}} \tag{4}$$

Uptake per unit organic matter is directly related to the concentration of a hydrophobic compound in solution and particle surface area available for adsorption. Organic content is often inversely related to particle diameter, however, and thus comparisons of K values and particle size may include effects of this variable. This would explain why over 90% of the variation in uptake by particles ranging in size from bacterial cells to sand grains can be accounted for by only considering differences in median particle diameter and DDT concentration.

Desorption of hydrophobic compounds from particles depends on the nature of the binding, compound solubility, and the length of time available for desorption. For example, DDT adsorbed to humic acid is not desorbed as readily as that on clay or sediment. Compound solubility is also critical in determining loss rates through desorption. Little DDT is lost from sand on rinsing, but lindane and dieldrin are readily lost in proportion to their solubilities. Thus, just as compound solubility determines the concentration available for adsorption to particle surfaces, it also determines desorption rates when concentrations in solution are reduced.

Initially pollutants retain the physical state in which they were introduced and in this state are acted on by physical forces. For example, pollutants associated with coarse-grained sediment dumped from a barge onto mud bottom may never become resuspended for further transport. Fine-grained particulate effluent may disperse widely before flocculating.

Once particles are suspended in a turbulent environment they interact and flocculate with each other and the naturally occurring particles thereby changing their size and hence their transport behavior. The exact mechanism of particle interaction and aggregate formation is poorly understood and only partly predictable at the present time.

Attraction due to molecular forces within the particles and/or adhesion due to organic coatings on surfaces is believed responsible for flocculation. Some mineral species appear to folcculate more readily than others. Observations with natural suspended particulate matter show that organic matter forms an integral part of flocs. This is not surprising since all surfaces in contact with sea water appear to become coated with organic material. The action of bacteria adhering to particle surfaces may be important in binding flocs. This would diminish the importance of mineralogy in controlling flocculation.

Sediment flocculates in sea water into aggregates the size of which are dependent on the grain size of inorganic particles. There is a logarithmic relationship between the modal size of the single deflocculated constituent grains. Flocculation occurs until all particles have approximately the same dynamic transport speed and no longer come into contact with each other. Since particle size and density rather than composition appear to be the controlling factor, the distinct flocculation behavior reported for minerals such as montmorillonite may be a product of their distinct grain size rather than their surface chemistry. Pollutant particles such as organic pulp mill effluent also become incorporated in the natural floc distribution, lose their individual physical characteristics and are transported as part of the natural sediment load.

The extent to which suspended particulate matter in fresh water is flocculated is not known. According to classical concepts massive flocculation takes place as unflocculated river sediment comes into contact with saline estuarine water. Some workers, however, have documented the importance of flocculation in lacustrine sedimentation. If bacteria are indeed a significant factor in particle flocculation, then flocculation should be as prevalent in fresh water as in the sea.

Microscopic observations of fresh water particulate matter show that a high proportion of the particles consist of aggregates. The grain size spectra show smooth nearly symmetrical distributions similar to those of marine particulate matter. Since all natural particulate matter contains particles from multiple sources with discrete grain sizes, the size distributions should be irregular multimodal if no interparticle reaction has taken place.

Once pollutants become associated with particles their fate is essentially dependent on the transport and dispersal of the particles themselves; they can be sedimented or transported and dispersed. Both can be transitional in that sediment can be eroded and resuspended or sedimented many times.

The transport and dispersal of particles is dependent on the transport rate of the water and on the relationship of the transport rate of particles to that of the water. Dissolved pollutants can be expected to disperse at the same rate as the parcel of water into which they were introduced. But particles usually have specific gravities greater than that of the water and gravity and inertia will give them a slower net motion. Only very small particles and particles with densities close to that of water will behave as dissolved substances. Progressively larger and heavier particles will have transport histories increasingly different from that of the water they are suspended in, and particle size and density are of primary importance in prediction of their transport behavior.

Models to predict transport rate of suspended sediment in relation to dynamic water transport are presently imperfect. The movement of large sand and silt particles transported as bedload with a rapid exponential decrease in concentrations away from the bottom is best understood. Their behavior has been studied in numerous laboratory and theoretical investigations. The fine-grained suspended load, composed mostly of cohesive material less than 16 microns, shows physical behavior different from that of the bedload and are easily distinguished from the bedload in grain size analysis of bottom sediments. Suspension of the material is largely dependent on levels of microturbulence and the highest concentrations are often encountered near the surface and near the bottom of a water body as well as in association with density layers within the water column.

At present the best guide to where particles of a given size will be deposited seems to be an empirical study of geological conditions along an aquatic pathway. For example, whether or not a pollutant associated with particles of a certain size can become deposited in a lake along a waterway or trapped in the turbidity maximum of an estuary may be determined by comparison of natural sediment grain size and that of the polluted material.

In conclusion it can be shown that pollutants entering the aquatic environment readily become associated with natural suspended particles. Dissolved compounds are adsorbed onto particles and substances in particulate form flocculate with other particles. The division between true solutions and colloidal suspension may be difficult to determine and is of no practical significance if both forms ultimately become associated with other particles.

Particle size and concentration are of prime importance in predicting transport and dispersal of pesticides. While the organic nature and surface charge of suspended particles affect adsorption, particle size and number (i.e., total surface area) may be the most important factor determining adsorption of non-soluble pollutants in water. Transport of particles after adsorption and flocculation is dependent on the relationship between grain size and the turbulence of the hydraulic environment.

SUMMARY

The results show that pesticides (chlorinated hydrocarbon pesticides in particular) are still a significant non-point source of contamination to Michigan rivers and consequently the bordering Great Lakes. The concentrations found are at the part per billion and trillion level but are still significant in terms of their effect on aquatic organisms due to biomagnification. The results of Mill Creek are supported by the fact that pesticides such as DDT and Dieldrin are found in Great Lakes fish and are responsible for the ban on commercial fishing for Coho salmon, etc.

There does not appear to be any reasonable mechanism for the elimination of these pesticides from the river and streams short of what has already been implemented (ban on the use of chlorinated hydrocarbon pesticides). Prevention of sheet soil erosion would certainly be a measure that would reduce the amount of pesticides entering the Great Lakes but would certainly not stop the introduction of all pesticides due to evaporation, drift, and other transport processes.